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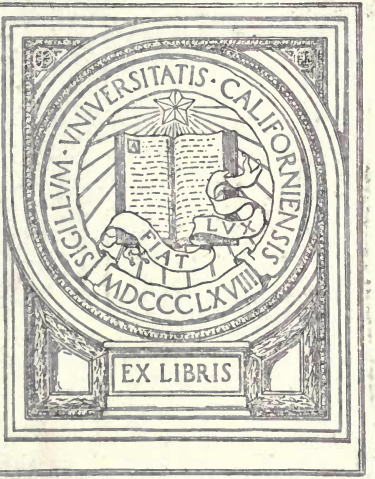

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WORLD-LIFE

OR

COMPARATIVE GEOLOGY.

BY

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Geology in framing its conclusions is compelled to take into account the teachings of other sciences.—SIR WILLIAM THOMSON.

La géologie suivie sous ce point de vue qui la rattache à l'Astronomie pourra, sur beaucoup d'objets, en acquérir la précision et la certitude.—LAPLACE.

Ewig zerstört, es erzeugt sich ewig die drehende Schöpfung,
Und ein stilles Gesetz lenkt der Verwandlungen Spiel.—SCHILLER.

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TO

HIS PUPILS IN THE UNIVERSITY OF MICHIGAN,

THIS VOLUME IS,

WITH PROFOUND CONSIDERATION,

AFFECTIONATELY INSCRIBED

BY

THE AUTHOR.

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GEOLOGY

PREFACE.

THE reader will find in the following pages a thoughtful view of the processes of world formation, world growth and world decadence. I have gathered together here many of the important facts observed in the constitution and course of nature, and have endeavored to weave them into a system by the connecting threads of scientific inference. I have aimed to incorporate the soundest and latest views published on the various branches of the subject; and have yet felt constrained, in so wide a field, and so unexplored in some of its nooks, to interpose my own conclusions in some cases where, perhaps, due diffidence should have restrained my pen. Inevitably the whole discussion is conducted from the standpoint of nebular cosmogony. This, as will be seen, has shaped the views presented on the accumulation of the materials for world formation, on the evolutions of nebulæ, stars and planets, on the all-important influence of tidal action in cosmic history, and on the grand cycle of cosmic existence. Appropriately the treatment ends with a historical sketch of the progress of opinion toward the lofty and inspiring generalization which the work attempts to set forth.

The motives which have prompted to the preparation of the work are four-fold.

1. I felt desirous that the general reader should be able to find within reach some simple, yet complete and connected, account of the development of the world and the system of material things to which we belong. Many of the grandest conceptions of modern science fall within this range. Many of the marked advances of modern investigation have contributed to the enlargement of our view in this field. Yet there is no work in the English language, if, indeed, in any language, bringing into one connected course of discussion all the questions properly incident to the activities of world

life. Different persons have ably investigated different branches of the general theme, as the reader will learn in the sequel, but no one has brought together and put in the form of popular statement the chief results of so diversified a range of researches. Many thousands of intelligent listeners have testified their appreciation of the expositions offered during fifteen years past from the popular platform; but these expositions have been necessarily descriptive and superficial, while many questions and many difficulties raised by the hearer had to be left unanswered. Here the speaker sits down to a sober talk with those who wish to listen further. I hope, therefore, the present work will find a welcome among the multitudes who have caught mere glimpses of the great doctrine, as well as the large class of readers in general who require something more substantial than our popular, fictitious tales of society.

2. I desired to offer the reader a portrayal of the grand system of the universe, and leave him with a profound impression of the omnipresence and supremacy of One Intelligence. The unity and interdependence of all parts of the cosmic mechanism, from nebula to river delta; the universality of nature's forces, and the uniformity of nature's modes of activity, all the way down from the galaxy to the little cascade in the glen, are facts of such stupendous and impressive significance as to stir the imagination and arouse the most torpid soul. This wonderful concatenation of things when once glimpsed by the timid doubter, must force a conviction of the continuity of material existence; and whoever has gained that conviction, and will faithfully question his own consciousness, will soon be convinced that that which is interpreted, and can only be interpreted, in terms of mechanism, cannot be self-originated, however remote its origin; nor self-acting, however vast its extent or incomprehensible its activities.

3. I desired to induct the earnest student of nature, young or old, into the vestibule of celestial mechanics, and leave him with an inspiration which should carry him on to the pursuit of the higher methods of physical investigation. I have hoped, also, to show him that the fields of truth are not fenced off from each other and limited by the narrow definitions of the sciences. The fences are all down, and it is all one domain. The geologist tries to work

out the constitution and life history of our planet. For the study of its accessible parts he needs to use the appliances and results of the whole round of the sciences. To its interior he cannot penetrate; but he finds the planet journeying on a course of change which leads directly from a state of high primitive incandescence; and, lifting his eyes, he beholds the incandescent state as a common incident in the vicissitudes of worlds. He cannot transport himself across the intervals of geologic æons, but he can gaze upon other worlds just entering upon states passed millions of years ago by our earth; or states, even, which will be reached by our planet some millions of years in the future. I have attempted to take the reader over the system of evidences from which he may thus reason in laying the foundations of a science which, from one point of view, may be styled the geology of the stars; and, from another, the astronomy of the earth. It is the science of Comparative Geology. It is Astrogeology. It yields to no science in the fruitfulness and fascination of its conceptions.

4. It has been a part of my purpose, also, to clear up the most serious difficulties encountered by belief in the nebular origin of our planetary system. At the present day the objections heard do not proceed to any considerable extent from proper representatives of scientific opinion, but from intelligent persons who fear that the interests of religious faith are jeopardized by the acceptance of any form of evolution. Some of these have honored me by very special attentions. They have challenged me to controversy, and their abettors have sometimes jeered me over my assumed inability to rise from the pile of ruins which has been made of me and my theory. I need not disguise the satisfaction which I feel in the arrival of the convenient time when these gentle gladiators shall discover themselves battering their blades against a wall.

While the fundamental conception underlying the course of reasoning here pursued is that of nebular evolution; and while the general method of the evolution conforms to the celebrated hypothesis of Laplace, it would be an error to conceive the present work an attempt to establish the "hypothesis of Laplace." In the first place, the general principles of nebular cosmogony were the growth of a century and a half; and the ideas contributed by Kant and Sir

William Herschel were certainly not less guiding and determinative than the services of the Marquis de Laplace. In the next place, the development of the doctrine has continued ever since the *Système du Monde* was published. Since the invention of the spectroscope, the nebular cosmogony has undergone important modifications. A number of the ablest investigators of the present generation have given their best efforts toward putting the general doctrine in a consistent shape. Nor can it be correctly said that the general theory remains still in the status of a hypothesis. In certain points of detail, opinion may still remain divided; but when a hypothesis has stood the scrutiny of three generations, and has become all but unanimously accepted by those prepared to form original opinions, as the real expression of a method in nature, surely, then, the time has passed when any person can advantageously illustrate his learning and sagacity by continuing to reproach the conception as "a mere hypothesis." If any "mere hypothesis" ever strengthened into the condition of a scientific doctrine, assuredly we find in the scientific world to-day the general features of a sound nebular doctrine.

In style and treatment the present work possesses a double character. The general reader may confine himself to the body of the discussion, unterrified by the nature of the foot notes, and find a simple, continuous treatment of the theme which, I hope, will satisfy his expectations. But if any one desires to know by what means some of the statements of the text have been established, he will find frequently in the foot notes the indications of simple mathematical operations, which may yield him some additional gratification. And if he feel prompted to pursue still further any branch of the inquiry, the accompanying references to the literature of the subject will enable him to follow the masters of science into their most recondite investigations. Thus, for one class, the book is suited to be read rapidly and laid aside; for another class it is a text book which may be studied.

The general conception of world life here set forth has occupied the author's thoughts for many years; and by writing and by popular lectures, as well as before university classes, he has endeavored to disseminate truthful and inspiring estimates of the method of the world's growth. He has stood for the defence of nebular theory

when it had few friends, and when its enemies were prompted as much by sentiment as by good reason. The great idea was fascinating; its magnificence took possession of the imagination, and its symmetry and coherence commanded rational conviction. It now commands the admiration and championship of the scientific world.

I feel that it is entirely improbable that all errors of statement have been avoided through all the details of the discussion. The intelligent reader will discover many points where I have had to cut loose from the moorings of high authority and venture among the breakers of independent speculation. It is only justice to myself, also, to state that all the main positions of the work were taken and reduced to writing more than two years ago. Many of those which at the time were new, or seemed to be new, were presented in public lectures as early as 1878 and 1879. Since these dates many advances in observation and in theory have been made, and not a few along those very lines which I had worked out. Since my first enunciations, Nordenskjöld, Tissandier and the British Association have done much to establish the doctrine of disseminated cosmical dust; Sir. W. Siemens has published his speculations on the sources of the sun's heat; M. Faye has investigated the geology of the moon; Mr. (now Professor) G. H. Darwin has published his beautiful analytical investigations of the evolution of a rotating viscous spheroid; and Rev. O. Fisher has collected in a handsome volume his researches on the physics of the earth's crust. If there remain any thoughts or suggestions which may fairly be ascribed to the author of this work, the scientific reader will find it out; and I have only to hope that they may be found adequately supported by evidence; and, finally, that the whole discussion may afford the reader a degree of pleasure equal to that experienced by the writer in bringing the discussion to its present shape.

University of Michigan, September, 1883.

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PART I.

WORLD-STUFF.

Antè, mare et tellus, et, quod tegit omnia, cœlum,
Unus erat toto Naturae vultus in orbe,
Quem dixêre Chaos; rudis indigestaque moles;
Nec quidquam, nisi pondus iners; congestaque eòdem
Non bene junctarum discordia semina rerum.—Ovid.

WORLD-LIFE.

CHAPTER I.

COSMICAL DUST.

I know no recent observation in physical geography more calculated to impress deeply the imagination than the testimony of this presumably meteoric iron from the most distant abysses of the ocean. To be told that mud gathers on the floor of these abysses at an extremely slow rate conveys but a vague notion of the tardiness of the process. But to learn that it gathers so slowly that the very star-dust which falls from outer space forms an appreciable part of it, brings home to us, as hardly anything else could do, the idea of undisturbed and excessively slow accumulation.—ARCHIBALD GEIKIE.

§ 1. METEORS.

WHENCE comes the "Dust of Time?" There is nothing around which the dust of time does not gather. It accumulates among the shelters of the mountain cliffs. It falls upon ivy-mantled towers and ruined walls, and creates a rooting place for many a hardy herb, and a nidus for countless living germs. It clogs the water-passages from our roofs, and fills our cisterns with soils yielded by the atmosphere. It gathers about deserted structures; it buries the foundations of columns and temples; and new temples are built upon foundations which have older foundations beneath them. The ancient cities of the East and of the West lie slumbering beneath the accumulations of this dust. Nineveh is recognized only as a mound of earth. Troy lies almost beneath the reach of Schliemann's spade. The cities of

Cyprus, the Morea, and the Roman Peninsula are but slowly undergoing fresh exposure to the light of day.

Whence the dust which has buried walls and towers and cities? Let us answer the question with soberness. The crumbling of wooden beams, and even of the solid stones, has supplied the larger portion of the débris which mantle the foundations of the ancient cities. Much of the soil which gathers upon roofs and in the crevices of old walls has been lifted by the winds from bare field and dusty street. Even the snowy summits of the Alps* become stained by terrestrial particles borne by upward currents into the mountain air. And yet I will venture the opinion that some dust comes to the earth daily *which had never belonged to the earth before.* Out from the depths of space — beyond the clouds — beyond the atmosphere — from a granary of material germs which stock the empire of the blue sky, comes a perpetual but invisible rain of material atoms — like the evening dew, emerging from the transparency of space into a state of growing visibility.†

This is a somewhat unfamiliar thought. I will endeavor to indicate the steps of evidence by which it is reached.

First, the METEORS yield both suggestion and proof. That mysterious visitant which paints its luminous streak along the evening sky — sudden, brilliant, but evanescent — what is it? And what does it signify? Mankind for ages have gazed upon it with contemplative awe. According to most recent scientific opinion, it is a mass of matter from outer space, which has become entangled in the exterior limits of our atmosphere, and, impeded in its movements by atmospheric resistance, has been

* M. Tissandier reports magnetic particles of iron dust at a height of 9,000 feet on the slopes of Mont Blanc, and other elevated positions.

† It has been quite a surprise to the author to find a similar conception thrown out by an anonymous writer several years since (*North American Review*, xcix, 28, note, July, 1864.)

overcome by the attraction of the earth, and deflected into a new path. It now moves obliquely toward the earth. The condensation of the air in front, caused by its rapid movement, develops an intense heat. The cold meteor is lighted up; it glows for an instant, but the heat becomes so intense that its entire mass sometimes is converted into vapor and strewn along the sky, to shine as a luminous streak after the bolide has ceased to pursue its course. The train of incandescent vapor retains its luminosity, at times, for one, two or five minutes, floating like a cobweb in the atmosphere,* and as it cools it fades from

* During the meteoric shower of November 14, 1868, Professor Maria Mitchell noted a train which lasted forty-four minutes, and underwent remarkable distortions of form. (See *American Journal of Science*, II, xlvii, 400.) The same was seen by Professor J. R. Eastman at Washington, to last thirty minutes (*Report*, November 23, 1868). The phenomenon has been discussed by Professor H. A. Newton (*American Journal of Science*, II, xlvii, 408). Changes of form and position of meteoric trains have been mentioned by Sir John Herschel and others. Professor E. E. Barnard, for instance, of Nashville, Tennessee, writes to *Nature* (xxv, 173, December 22, 1881) that a meteoric train remained visible, November 16, to the naked eye, six minutes, and with telescopic aid, fifteen minutes, and floated meantime, four degrees. On the contrary, Admiral Krusenstern states that he saw, during his voyage around the world, the train of a fire-ball shine for an hour after the luminous body itself had disappeared, and scarcely move throughout the whole time (Krusenstern: *Reise*, Th. i, S. 58).

If the visibility of the train results from incandescence, it is difficult to understand how it remains so long in an assemblage of particles fine and buoyant enough to float in the upper atmosphere. Is it an electric or a phosphorescent glow? Humboldt in a note (*Cosmos*, Ott.' trans. Harper ed., i, 142) says "several physical facts appear to indicate that in a mechanical separation of matter into its smallest particles, if the mass be very small in relation to the surface, the electrical tension may increase sufficiently for the production of light and heat." Thus, while we are forced to admit the first flash of a meteoric streak as implying actual incandescence, it seems not improbable that the fainter and prolonged glow is electric. In this connection I am reminded to cite a passage from Professor Joseph Lovering: "Finally, I may notice the light enjoyed in cloudy nights which cannot, Arago supposes, come from the stars, but from the phosphorescent clouds. It is never so dark out of doors as in a subterranean apartment, or in a room without windows. During the dry mist of 1783, the sky was as bright as during the full moon when overclouded. Is this light the glow-discharge of electricity? If so, has the solar light the same electrical origin more intensely developed? And is the colored light which Nicholson saw in the clouds on the 30th of July, 1797, the result of processes similar to those that give a color to certain of the stars which differ from the white sun-light?" (Lovering, *Patent Office Report*, 1855, *Agriculture*, 356.)

view. But let us not lose sight of the matter which underwent ignition; it is not annihilated; it has not been returned to the regions beyond our atmosphere; those are physical impossibilities. Unseen, unheard, millions of particles of cooled vapor remain floating in our air. Being ponderable, being mineral and mostly metallic, they must settle toward the earth. They are plunged into the vortices of the winds; they are soaked up by aqueous vapors; they are floated by clouds, they are washed down by rivers and added to the volume of the globe.*

That this conclusion is well founded we have abundant evidence. Every one understands that the atmosphere is freighted with minute solid particles. These were elaborately investigated by Ehrenberg thirty or forty years ago, who, like Pasteur and Tyndall in more recent researches, directed attention more especially to organic substances, particularly minute germs and bacterial organisms. Few people understand that the atmosphere bears also a large proportion of mineral substances, some of which must, almost to a certainty, have an extra-terrestrial origin. A careful compilation of facts has been made by M. Gaston Tissandier in his work on atmospheric dust.†

As to atmospheric dust of terrestrial origin, investigation shows that the larger part is taken up by winds from the deserts of Sahara and Gobi. The African dust has descended in scores of recorded showers in all parts of Europe, as well as in the Atlantic ocean along a belt of 1,500 miles, and as far as 300 miles from land. The Mongolian dust falls chiefly in northern China, and is conceived by Baron von Richthofen to be the source of a vast

* The foregoing obvious inferences were penned and made part of a lecture in 1877. Since that date the writer has discovered a large amount of evidence bearing on the question of cosmical dust, as the statements and references in the next following paragraphs will show.

† Tissandier: *Les poussières de l'air*, Paris, 1877. See also *Popular Science Monthly*, xvii, 344-50, July, 1880.

geological deposit known as loess. The volcanoes of Java, Central America and Iceland have also emitted astonishing volumes of dust which was floated hundreds of miles. Amongst organic substances found in nearly all parts of the world sometimes occur enormous quantities of pollen cells from forests of coniferous vegetation.* The particles of smoke arising from western forest and prairie fires are often wafted from Michigan and Wisconsin to Montreal and New York. There is no doubt that the characteristic smokiness of the atmosphere during the mild period in November following the occurrence of the first killing frosts, and known in America as the Indian Summer, is simply the smoke arising from the autumnal burnings of the recently killed and well dried vegetation of thinly settled districts. It may hence be inferred that this feature of the Indian Summer will grow less characteristic as settlement more completely clears and cultivates the surface.

But atmospheric dust of terrestrial origin has no bearing on our search for world-stuff. Among the earliest to suggest a cosmic origin for certain forms of atmospheric dust were Ehrenberg and Arago. The latter in his Popular Astronomy† says it may be presumed that showers of dust do not differ materially from ordinary meteoric showers. The dust, he says, appears to contain the same substances as meteoric stones. Ehrenberg states that one element in the colored snows examined by him was iron, and he expresses the hope that scientific men would accu-

*The writer recalls an occasion in 1853 when in Alabama, on the morning after a shower, a yellow and sulphur-like deposit was left wherever the water had been accumulated. Investigation showed the substance to consist of pollen grains; and as the cypress swamps and pine forests of the Gulf region were then in flower, the explanation was obvious. Similar "sulphur showers" have been since reported as far north as the Ohio river, and also in the countries of southern Europe. A case is recently reported in Iowa by C. E. Bessey. *Amer. Naturalist*, xvii, 658, June, 1883.

†Arago: *Astronomie Populaire*, t. iv, 208. See also *Œuvres complètes de François Arago*, t. xii, 293, 463, etc.

mulate the substance in quantity, and compare it in this state with fragments of aërolites, and inspect microscopically the smallest globules. Baron Reichenbach in 1864* insisted on the probability that meteorites exist in the form of granules and dust, that they descend to the earth and add something to its quantity of matter. He also was apparently the first to detect nickel and cobalt in atmospheric dust, and these furnish the critical demonstration of its meteoric origin. M. Daubrée, in his celebrated memoir on meteorites,† speaking of the meteorite of Orgueil, says it is "very instructive in reference to the existence of meteoric dust," and proceeds to explain how the disintegration of such a body would supply it. Among the first to produce evidence in support of the theory of the cosmic origin of certain portions of the atmospheric dust was Baron A. E. Nordenskjöld.‡ He reported large patches of arctic ice covered with a gray diatomaceous powder mingled with grains of magnetic iron surrounded by iron-oxide, and containing also probably carbon. Similar deposits were reported from snows from the neighborhood of Stockholm, from the interior of Finland and from Spitzbergen. He reports the detection of nickel and cobalt in dust from the middle of Greenland, and states that he is personally convinced that certain hail from near Stockholm was formed around particles of cosmic origin floating in the air and falling continually to the earth. He also indicates the presence of a brown carbonaceous material like that afforded by the meteoric iron from Ovifak, which is characterized by a very disagreeable odor and *seems to be organic.* Baron Nordenskjöld has

* Reichenbach, *Poggendorff's Annalen*, cxxiii, 368-74, 1864; *Cosmos*, 29 Dec. 1864.

† Daubrée, *Journal des Savans*, 1870.

‡ See a note by M. Daubrée in *Comptes Rendus*, lxxvii, 464, 18 Aug. 1873, and lxxviii, 236, 26 Jan. 1874. Also *Poggendorff's Annalen*, cl, 154, 1874, and *Am. Jour. Sci.*, III, ix, 145-6.

more recently reported further observations.* He states that the snow of the coast of the Taimur peninsula was covered with yellow specks of carbonate of lime of an unusual form of crystallization, and these he believed to be of interplanetary origin. The carbonate of lime found by others, as well as all organic traces, has generally been referred to a terrestrial origin; but this, after all, may be an error.

At the meteorological station of Yeneseisk, Marx collected a quantity of brick-red dust which was brought down from the atmosphere during a gale, accompanied by snow and rain, October 31, 1881. An examination of this by Professor Lenz shows it to consist of iron, nickel and cobalt; and he entertains no doubt of its cosmical origin, pointing out the fact that it was observed on a day very near to the appearance of the November meteors.†

M. Tissandier has made quite extensive researches on atmospheric dust, and has put beyond question the meteoric origin of certain portions of it. Many grains and minute globules of iron are met with in these dust-falls, which appear to have been fused; and it is shown that in certain cases, nickel and cobalt are present in the iron, precisely as in siderolites. But in other cases these substances are wanting, and these are cases where other indications point to a terrestial origin. These grains of magnetic iron have been collected from a great variety of situations—from the summit of Mont Blanc, from rains recently fallen, from the towers of Notre Dame cathedral in Paris and many other cathedrals, from the borders of Lake Lehman, from the hospice of St. Bernard and from many localities in distant countries. Everywhere are

*Nordenskjöld: *The Voyage of the Vega round Asia and Europe.* Translated by Alexander Leslie, 2 vols, London, 1881.

†Lenz in *Izvestia* of the Russian Geographical Society, 1883, cited in *Nature*, xxvii, 422, March 1, 1883.

found these iron globules bearing the unmistakable marks of fusion. The following figures are copied from M. Tissandier's work :

Fig. 1. Corpuscles of Magnetic Iron, From the Snow of Mont Blanc at the Height of 2,710 Metres. × 500.

Fig. 2. Corpuscles of Magnetic Iron Collected from Rain Water at Sainte Marie du Mont. × 500.

Fig. 3. Corpuscles of Magnetic Iron from the Dust Collected in the Unfrequented Towers of Notre Dame de Paris. × 500.

Most of the writers who recognize the meteoric origin of these grains conceive them as minute meteorites, while to me they seem rather to be the cooled particles of the volatilized bolide. When of small size, the bolide is completely consumed, when too large for a destructive heat to penetrate to its centre during the brief interval of the body's descent through the atmosphere, it is only the surface which undergoes fusion, and this is swept off by the violent impact of the air, and broken into countless minute particles. Hence the exterior of a fragment of meteoric iron presents those peculiar rounded bosses and concavities developed on the surface of melting ice.

Occasionally these bolides attain to terrific dimensions. The accompanying illustration, also from Tissandier, represents the bolide which preceded the fall of meteorites at Queengouck, India, on the 27th of December, 1857. The train shows the particles of molten mineral brushed off by the impact of the air. The drawing was executed by Lieutenant Aylesbury, an eye-witness of the phenomenon, and was first reproduced by Haidinger in his *Étude sur la chute Queengouck*.

If Mr. John Aitken's theory is correct, that the presence of solid particles is the condition of vapor-condensation, then the highest clouds of our atmosphere reveal the presence of a fine dust, and this very probably is of a cosmic character.*

A committee of the British Association appointed to investigate this subject, reported through Professor Schuster in 1882,† that rounded particles of iron containing nickel and cobalt have been found in many situations, and we are constrained to ascribe them to a cosmic origin.‡

Thus the evidence of the perpetual arrival of foreign matter from the interplanetary spaces seems conclusive.

* See *Nature*, xxiii, 195-7, December 30, 1880.

† See abstract in *Nature*, xxvii, 488.

‡ The reader will find a summary of the principal cases in the work of Tissandier. The following are some notices of more recent date. Tacchini reported iron in atmospheric dust, *supposed* to be from the Sahara (*Académie des Sciences*, 28 June, 1880). Professor Sylvestri of the Catania Observatory, reported a dust-fall with much metallic iron in Sicily, March 29-30, 1880 (*Atti dei R. Academia dei Lincei*, fasc. 6, May, 1880; *Nature*, xxi, 574, xxii, 257). On Sicilian dust-falls, which have been particularly frequent, see Lancetta in his Synthesis of meteorological observations in Modica and Syracuse, on the fall of meteoric powders from the end of 1876 to April 16, 1880 (*Revista Scientifica-Industriale*, No. 15, August 1880). M. Daubrée reports further dust-falls at Autun, April 15, 1880, and in the Departments of the Basses-Alpes, Isère and Ain, France, April 21-25, 1880 (*Comptes Rendus*, 10 May, 1880), as also in Algiers, April 24-26, 1880 (*Nature*, xxii, 76). Mr. Murray of the Challenger found meteoric dust in the dredgings from the bottom of the sea. (See Archibald Geikie: *Geological Sketches*, ch. vi, Humboldt Library, No. 39, p. 35.) Professor D. Kirkwood has reported a dust-fall in Indiana, March 28, 1880 (*Popular Science Monthly*, xvii, 553).

FIG. 4. FALL OF A BOLIDE AT QUEENGOUCK, INDIA, INCLUDING THE VILLAGE OF BASSEIN FOR COMPARISON.
From a drawing by Lieut. Aylesbury.

An insignificant addition to the earth's mass, the reader may think. But let us examine. Ehrenberg states that the mass of dust which fell at Lyons in 1846, over an extent of 400 square miles, was estimated by the French savans to be 7,200 quintals, or 793 tons. Chladni calculated that the aërolites enumerated by him as falling between 1790 and 1818 weighed 600 quintals, and on this basis it has been held that the daily fall of atmospheric dust must be millions of quintals. Ehrenberg calculated that 243 quintals, or 27 tons, of red dust fell with snow over 100 square miles in the mountains about Salzbourg, on the 6th of February, 1862. According to M. Calvert, 15 French tons per square mile fell in Carniola on the 5th of April, 1869. Baron Nordenskjöld says: "I estimate the quantity of the dust that was found on the ice north of Spitzbergen, at 0.1 to 1 milligram per square metre, and probably the whole fall of dust for the year exceeded the latter figure. But a milligram (.0188 grain) on every square metre of the earth amounts for the whole globe to five hundred million kilograms (say half a million tons)."

Some of these estimates embrace, undoubtedly, dust transported from the Sahara. Let us then direct attention to unquestioned meteoric matter. It is said on good authority, that seven and one-half millions of meteors bright enough to be seen by the naked eye, pass through our atmosphere, on an average, every twenty-four hours, "and this number must be increased to four hundred millions if those be included which a telescope would reveal."* On special occasions they are seen to fall like

*Schellen: *Spectral Analysis*, Am. ed. 404. Mr. Denning (*Observatory*, April 1883) states as a result of a rough computation, that about two hundred and sixty telescopic meteors appear hourly in a space fifty degrees square (using a ten-inch reflector and comet eye-piece), while the number of naked-eye meteors on the same space averages only twelve; so that the proportion of telescopic and naked eye meteors is as twenty-two to one. If then we assume seven and one-half millions as the number of naked-eye meteors in the whole

drops of rain in a brisk shower. Arago estimated that he saw two hundred and forty thousand in three hours, from his place of observation, on the 12th of November, 1833. My father, who witnessed this remarkable shower, has often described the spectacle which he beheld before daylight on that memorable morning, in such terms that it is easy to believe that hundreds of millions passed before his eyes within a space of one or two hours. The sky was woven into a network of fiery fibres, and the snow on the ground glowed with a red illumination. Suppose each meteor to contain but ten grains of matter, if four hundred millions enter our atmosphere every twenty-four hours, this is two hundred and eighty-six tons daily, or one hundred and four thousand three hundred and fifty-two tons every year. In one hundred million years this amounts to ten million four hundred and thirty-five thousand two hundred millions of tons.* Now, while a few grains of matter in a state of intense incandescence may emit sufficient light to be visible at a distance of twenty to fifty miles, it is not probable that the average bolide of observation has a mass as low as ten grains. Thousands of them possess too great a mass to be vaporized in the brief time spent in passing through the atmosphere; and then they reach the earth as meteorites, and constitute meteoric stones, aërolites and siderolites or meteoric iron. In this condition they have been found weighing several pounds, and occasionally several tons. In January, 1879, a meteoric body struck a house in Indiana, and in its

sky in twenty-four hours, there should be one hundred and sixty-five million telescopic meteors in the same time. Mr. Denning's estimates, however, are far below the figures given by Schellen and here used.

*Nevertheless this would produce a film only one-twelve hundred and fiftieth of an inch thick over the whole earth. M. Dufour (*Comptes Rendus*, lxii, 840) has raised the question whether the addition of meteoric matter to the earth may not be the cause of the secular acceleration of the moon; but he has evidently exaggerated the importance of these additions. This acceleration moreover is otherwise explained.

descent to the cellar, passed through the body of a man in bed.* The intense and unequal heating of the exterior and interior portions of the larger meteorites is probably the cause of those occasional explosions which scatter brilliant fragments over areas miles in width, and send the report of a detonation to human ears. Many meteoric masses when found, present a surface smoothed and wrought into conchoidal depressions, and presenting, in many respects, the appearance of a mass of rapidly melting ice. Sometimes many distinct furrows have been sunken in the surface, showing the channels along which the liquefied portions have been driven off behind, as the body shot through the air.

Chemical analysis shows that meteorites are composed of well known terrestrial substances. The most abundant element is iron, but, in union with this, nickel always occurs, and sometimes, also cobalt, copper, tin and chromium. Other elements are silicon, oxygen, hydrogen, sulphur, phosphorus, carbon, aluminium, magnesium, calcium, sodium, potassium, manganese, titanium, lead, lithium and strontium. The silicon generally appears as silicates of various bases. Among the silicates, olivine is noteworthy as a greenish glassy mineral common in volcanic rocks. Augite is another silicious mineral of similar terrestrial associations.

Meteorites have been observed at calculated altitudes of forty-six to ninety-two miles. They move with velocities ranging from fourteen miles to one hundred and seven miles a second. If we suppose a dark mass of matter moving at the rate of twenty-seven miles a second, to meet the earth, itself moving nineteen miles a second, and consider that the earth's attraction would develop an

*This, according to the *Indianapolis Journal*, was Mr. Leonidas Grover "who resided in the vicinity of Newtown, Fountain county, near Covington, Indiana."

additional velocity of six miles a second, we have an aggregate velocity of *fifty-two miles a second.* With such a velocity, some of these meteorites plunge into our atmosphere. It hence becomes intelligible that even in the most rarefied portions of the atmosphere, the condensation in front of a meteorite moving with such velocity must develop sufficient heat to result in incandescence, and even in volatilization. Sir William Thomson determined by experiment that a body moving through the air at the rate of one hundred and twenty-five feet per second, develops one degree of heat, and that with increased velocities, the increase of heat is proportional to the square of the velocity. From this principle it is easy to calculate that a velocity of four thousand feet per second would cause a heat of over one thousand degrees, and a velocity of forty-four miles per second would give a temperature of three or four million degrees. Long before any such temperature is actually reached, the substance of the meteoroid is dissipated in vapor.

At the beginning of this century, it was generally believed that aërolites were either condensations of vapors arising from the earth, or were projected from lunar volcanoes. It has indeed been argued by Chladni,* by Halley,† and by Lichtenstein,‡ that aërolites are of cosmic origin; but this point was not clearly established until 1833, when Professor Olmstead showed that the November meteorites of that year all radiated from one point in the constellation Leo, and could not, therefore, have partaken of the rotary motion of the earth. This conclusion was eagerly accepted by Poisson. Arago was the first to suggest § the periodicity of meteoric showers; but it required

* Chladni: *Ueber den Ursprung der von Pallas gefundenen und anderen Eisenmassen.*

† Halley, *Phil. Trans.*, xxix, 161–3.

‡ Lichtenstein, *Göttingen Taschenbuch.*

§ Arago, *Annuaire*, 1836, p. 297.

a third of a century more to attain to a clear conception of the theory of meteoric phenomena as now understood.

It has been shown by the researches of H. A. Newton,* Schiaparelli, Le Verrier, Peters, Adams, Weiss, and others, that the meteors which fall within our atmosphere at regular periods, in August and November, are derived from swarms of meteoric bodies revolving about the sun in orbits which intersect that of the earth. (See Figure 5.) The source of the August meteors is believed to be a cosmical cloud forming a ring around the sun. The aphelion of this ring is 1,732 million miles beyond the orbit of Neptune.† The plane of the ring, or more properly, ellipse, is inclined at an angle of 64° 3′ to the plane of the earth's orbit, and its orbital motion is contrary to that of the earth. The November shower occurs once in thirty-three years; and hence, though the meteoric orbit must intersect that of the earth, so that the earth passes it annually, the meteors do not stretch in a continuous ring around their orbit. From the fact that the meteoric belt is intercepted by the earth only once in thirty-three years, it was shown by Professor Newton that in $33\frac{1}{4}$ years the swarm must make one revolution, or $32\frac{1}{4}$, $34\frac{1}{4}$, $65\frac{1}{2}$ or $67\frac{1}{2}$ revolutions; and that, to test which of these is the correct number, we must investigate the possible influence of the several planets upon the movements of the swarm. The investigation was made by Schiaparelli of Milan, and about the same time, by Professor Adams of England; and it was thus demonstrated that the $33\frac{1}{4}$ years period is the only one which satisfies all the conditions.‡ On this theory of

*See Professor Newton's remarkable succession of contributions to our knowledge of the phenomena of meteorites, and his sagacious discussions of these phenomena, and inferences from them, in the successive volumes of the *American Journal of Science*, from 1861 to 1873.

†This is based on Oppolzer's determination of a period of 124 years, and is obtained by Kepler's third law. But the period is not accurately known.

‡Sir William Thompson, Address at Edinboro Meeting British Association, *Amer. Jour. Sci.*, III, ii, 289, Oct. 1871.

the orbital period of the meteoric cloud, it is apparent that it stretches for a long distance along its orbit, since it is intercepted by the earth on the two Novembers following the principal shower, though the meteoric fall is greatly diminished at the second and third intersections. Assuming the meteoric period to be thirty-three years, the cosmic cloud must therefore stretch over one-eleventh of the whole orbit. The motion of this cloud is also retrograde; the inclination of the orbit is 14° 41′, and its major axis is ten and one-third times the mean diameter of the earth's orbit. The node or point of intersection with the earth's orbit has a motion of 52″.4 annually in the direction of the meteoroidal motion. This meteoric orbit is therefore, like the other, similar to that of a comet; and, if it were less inclined to the ecliptic, would probably serve as a source of meteoric showers to Mars and the Asteroids.

The relations of these two principal meteoroidal orbits to the solar system are intended to be illustrated by the diagram, Figure 5. The orbits of the earth, Jupiter, Saturn, Uranus and Neptune are here supposed to lie in one plane, and are so situated that the eye takes a perspective view across the plane. The relative magnitudes of the orbits are not accurately represented, and Neptune's orbit is shown only in very small part. The earth's orbit is so placed that the major axis does not correspond with the longest dimensions shown in the perspective. The same is true of the other orbits. The extremities of the earth's major axis show approximately the positions of the earth at the solstices, June 21st and December 21st. The arrows show the directions of the motions represented in the diagram.

The orbit of the November swarm of meteoroids is shown as having an angle of 14° 41′ with the plane of the Earth's orbit. The greater part of this orbit lies below the

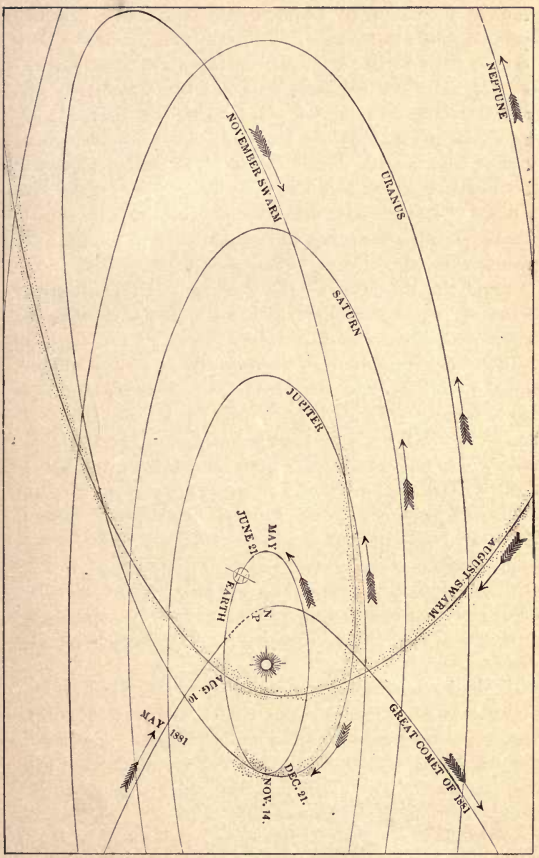

FIG. 5. ILLUSTRATING THE POSITIONS OF THE AUGUST AND NOVEMBER METEOROIDAL SWARMS.

plane of the ecliptic. The motion of the swarm is nearly opposed to the Earth's motion. The swarm reaches its perihelion a little before it crosses the Earth's orbit on November 14. The Earth passes on, after the crossing, to the winter solstice and beyond. The train, meantime, is trailing across the path of the Earth at the November point. It is of such length that it continues to trail across until the Earth has reached the November point again and again. It is, therefore, many millions of miles in length. The aphelion point of this meteoroidal orbit is a little more remote than the orbit of Uranus.

Similarly, the orbit of the August swarm of meteoroids is represented as having an angle of 64° 3′ with the plane of the Earth's orbit. It is, therefore, turned up so that the view presented in the figure is much less oblique, and the orbit appears very broad. The longer axis of the orbit, however, is greatly foreshortened, and the two branches must be conceived as retreating into the far distance, a little to the left of the direction of the line of sight. The aphelion, which is one thousand seven hundred and thirty-two million miles beyond the orbit of Neptune, is almost included in the diagram. This swarm is four million miles broad, and reaches quite around its orbit, though the meteoroidal bodies are not uniformly distributed. Hence the August shower is of annual occurrence, while the brilliancy of the display is very variable.

Several other remarkable cosmic clouds have been recognized, and the following table of the best established has been arranged from the *Annuaire du Bureau des Longitudes* for 1881. The table gives the epoch, right ascension and declination of the principal radiant point in each cloud.

TABLE OF METEOROIDAL SWARMS.

Epochs.		Radiant Points. I. R.A	I. Dec.	II. R.A	II. Dec.	III. R.A	III. Dec.	IV. R.A	IV. Dec.
I	Jan. 2 to 3.	238°	+45°						
II	Apr. 12 to 13....	273°	+25°						
III	Apr. 19 to 23....	267°	+35°	238°	−30°	225°	+52°	204°	−18°
IV	July 26 to 29	342°	−34°						
V	Aug. 9 to 14	43°	+57°	345°	+50°	294°	+52°	9°	−19°
VI	Oct. 19 to 25	74°	+25°	95°	+15°	112°	+29°		
VII	Nov. 13 to 14...	148°	+24°	53°	+32°	279°	+56°		
VIII	Nov. 27 to 29....	25°	+45°						
IX	Dec. 6 to 13	105°	+30°	149°	+41°				

Notes. Swarm II is perhaps only a stray portion of III. Of the latter the Chinese records mention many recurrences, and the swarm is thought connected with the Comet I 1860. Swarm IV is spread over the whole heaven of the northern hemisphere, but in the southern, the principal radiant is as indicated. Swarm V is known as the Swarm of St. Lawrence, also as *Perseids*. According to J. J. Schmidt, there are not less than forty radiant points in all. These meteors are connected with the Comet III 1862. Swarm VI has many radiants indicated in the course of many years. Swarm VII is known as the *Leonids*, which revolve in the orbit of the Comet I 1866. Swarm VIII is in connection with the Comet of Biela-Gambart, which in 1872 gave origin to a fine display of meteors. Swarm IX is composed of small bodies, but exceptionally brilliant. It possesses numerous radiant points.

Here are given the positions of twenty important radiant points, each of which may really appertain to a distinct swarm, though exhibited simultaneously with other radiants. But besides these are numerous others; and if each separate radiant corresponds to a distinct swarm, moving in a distinct orbit, we have knowledge of more than a hundred meteoroidal orbits which pass in close proximity to the earth's orbit. This, in the opinion of some physicists,

is the fact. In truth, there is scarcely a night in the year, as every one can testify, when some meteors may not be seen. If these bodies are generally connected with swarms, large or small, there is scarcely a night when the earth's path is not intercepted or grazed by a meteoroidal train. A similar number must pass during the day; and we should thus have indications of over seven hundred passing annually in close proximity to the earth, each of which might be 794,000 miles in diameter. These trains are as clouds of sand floating in space, but describing regular orbits about the sun. The constituent bodies may be conceived as possessing all dimensions, from a molecule of matter to the size of an asteroid.

Now, let it be borne in mind that the cosmic clouds of whose existence we have learned, are only such as have orbits *intersecting* or grazing that of the earth. Let it be remembered, too, that of all meteoroidal orbits intersecting that of the earth, only such can be revealed as are traversed by the meteoroidal swarm, at the point of intersection, *at the same time* that the earth happens to be passing the same point. How many must there be located in such positions as not to be brushed by the earth's atmosphere, or impressed by the earth's attraction. The intersection of one of these meteoroidal orbits by that of the earth is almost like striking a solitary line by a random shot in infinite space. The interception of a swarm is like hitting a particular point. Millions of chances against it. How many meteor swarms have we a right to assume as probably sweeping in all conceivable directions at all conceivable distances, within at least the limits of our system, about this central sun? Could our vision be unsealed, we should behold the infinite firmament dotted with meteors hurrying to and fro, as snow-flakes in the wildest wintry storm.

From this survey of facts and theories it appears manifest that the "dust of time" comes down to us out of the

interplanetary spaces. These meteoric matters are samples of the stuff which exists in the far regions where the stars are shining. It comes to us and we handle it and investigate it, and find it exactly like the stuff from which our world is made. We are not isolated, as we had thought, from the starry realm. Even the meteors are messengers — flaming messengers — bringing us these tidings from distant provinces, and assuring us that the government whose details are administered upon our earth is loyally recognized in the regions lying on the distant verge of the visible universe.

§ 2. THE ZODIACAL LIGHT.

Secondly, the ZODIACAL LIGHT yields evidence of cosmical matter floating in space. This is a faint yellowish light which rises like an ill-defined cone from the western horizon just after sun-set during winter and spring, and from the eastern horizon just before sun-rise in summer and autumn. It extends very nearly in the plane of the ecliptic; and hence, when the direction of the ecliptic is strongly inclined toward the horizon, this faint light is obscured by the atmosphere, and remains unnoticed. It sometimes extends nearly to the zenith, and there are many accounts of its appearance, especially in tropical latitudes, in the western and eastern horizons, at the same time,* though the brightness is much less in the horizon opposite the sun.

Polariscopic study of the light shows it to be polarized

* For a valuable mass of observations on the zodiacal light, with a large number of graphical illustrations, see Chaplain George Jones' memoir in *Report U. S. Japan Expedition*, vol. iii, as also a brief statement in *Astronomical Journal* No. 84, and *Amer. Jour. Sci.*, II, xx, 138-9. For other data see M. Houzeau's memoir in *Astronomische Nachrichten*, 1843, and the valuable paper of Prof D. Olmsted in *Am. Jour. Sci.*, II, xii, 309-22, embracing the best graphical delineation known to the present writer. For historical and critical notes see Humboldt: *Cosmos*, Otté translation, i, 137-44.

in a plane passing through the sun. The amount of polarization is 15 to 20 per cent. This result shows that the light is derived from the sun, and is reflected from solid matter consisting of small bodies apparently not differing in their nature from terrestrial minerals.* Spectroscopic study of the light leads to the same conclusion. Its spectrum is continuous, and is sensibly the same as that of faint sunlight or twilight.† It seems well settled, therefore, that we have in this phenomenon a true example of cosmical dust floating in space and rendered luminous, like the dust rising from our streets, by the reflection of solar light. This happens to be very exactly the same view promulgated by Dominicus Cassini in 1730, who was the first to devote elaborate study to this phenomenon.

The arrangement of these cosmical matters in relation to the sun and the earth has been much discussed. Laplace concluded that they could not belong to the atmosphere of the sun, since the form is far too lenticular for a body rotating no more rapidly than the sun.‡ Still, he suggests, as Cassini had done at an earlier date, that the matter of the zodiacal light may surround the sun as a ring; and he suggests, also, an origin for it, in conformity

* A. W. Wright, *Am. Jour. Sci.*, III, vii, 451-9.

† A. W. Wright, *Am. Jour. Sci.*, III, viii, 39–46. Some other observers, notably MM. Respighi and Angström, have reported a bright yellow line in the spectrum; but Prof. Wright found it present only when the *aurora borealis* was displayed, and was never seen when the aurora was absent. Father Secchi's experience was the same. See, also, observations by Prof. Piazzi Smyth, *Monthly Notices, Roy. Astr. Soc.*, June 1872, p. 277, and M. Liais, *Comptes Rendus*, lxxiv, 262, 1872. See further, R. A. Proctor, *Monthly Notices*, xxxi, No. i, Nov. 11, 1870.

‡ Laplace: *Système du Monde*, Liv. iv, ch. x, ed. 1824, p. 270. Nevertheless Father Secchi says, in view of the changes in the color of the zodiacal light, at the time of perihelion passage of the comet of 1843, "cela prouverait donc que cette lumière n'est que l'atmosphère solaire, et non pas un anneau détaché" (*Le Soleil*, 2d ed., ii, 433). It is generally represented that Kepler had thought the zodiacal light to be a portion of the sun's atmosphere, but Humboldt maintains (*Cosmos*, i, 140, note) that this "limbus circa solem, coma lucida" has no reference to this phenomenon.

with his celebrated hypothesis respecting the origin of the planets. "If," he says, "in the zones abandoned by the atmosphere of the sun, there existed any molecules too volatile to unite with each other or with the planets, they ought, in continuing to circulate about that body, to present all the appearances of the zodiacal light, without offering any sensible resistance to the various bodies of the planetary system, for the reason either of their extreme tenuity, or because their motion is almost exactly the same as that of the planets which encounter them."*

Whether this is a correct conception of the zodiacal light or not, it is generally agreed that the phenomenon arises from a ring of meteoroidal bodies encircling the sun, nearly in the plane of the ecliptic, and probably rotating like the rings of Saturn. But considering that the phenomenon has so frequently been witnessed in the east and west at the same time, it is necessary to assume that while most of the matter lies within the earth's orbit, some portion extends beyond that limit. Accordingly, the earth moves within the assemblage of particles. Consequently, unless they have precisely the same velocity as the earth, they must by their collisions offer a resistance to the earth's motion. The entrance, then, of these zodiacal molecules into the earth's atmosphere might present meteoric phenomena.

A different location of this annulus is maintained by others. Rev. George Jones, before cited, argues that the appearance of the light in both horizons at the same time is evidence that the annulus surrounds the earth. Professor Stephen Alexander† for similar reasons rejects all heliocentric theories, and maintains that the annulus is an

*Laplace: *Système du Monde*, Note vii, 415–6. M. Roche also regards the matter of the zodiacal light as a remnant of the primitive nebula.

†S. Alexander, *Smithsonian Contributions*, xxi, No. i, 68. In opposition to the geocentric theory see F. A. P. Barnard, *Am. Jour. Sci.*, II, xxi, 217–37; and Commander Charles Wilkes, *Proc. Amer. Assoc.* 1857, 83–92, 399–401.

appurtenance of the earth, lying nearly in the plane of the moon's orbit, and that it is girdle-shaped instead of discoid. He calls it "a nebulous girdle revolving around the earth in the same time and general direction with the moon." He compares it, like Chaplain Jones, with the dusky ring of Saturn, though differing in shape. The very unequal intensity of the light in the horizon opposite the sun is a fact at variance with the geocentric theory. The original conception of Cassini and Laplace seems most conformable with all the facts; and there is much reason in the supposition also, that this ring is a remnant of the primitive nebula, detached according to the principles which I shall hereafter explain. One circumstance, however, indicates that this phenomenon may be something of modern origin; since, of all the acute observers of the heavens in ages past, from the Babylonians to Tycho and Kepler, none make any allusion to it before the latter part of the seventeenth century. Childrey, in 1661, gives the first clear and unmistakable mention of it.* If it is indeed, a phenomenon of modern origin, it cannot, of course, be viewed as a vestige of the work of planetary evolution. We must seek for some appropriate existing action and process, and we may direct our inquiries to the seemingly repulsive power exerted by the sun in the radiant forms of the solar corona and in the tails of comets.†

*Childrey: *Britannia Baconica*, 183, cited by Humboldt.

†It may be mentioned as a matter of interest that Prof. D. Olmsted as early as 1834 (*Am. Jour. Sci.*) suggested a nebulous body revolving around the sun as the source of the November meteor shower of 1833, and he identified this with the zodiacal light in 1851 in the memoir before cited. The same suggestion was made in 1836 by M. Biot as to the nebular origin of the meteors. Commander Wilkes (*op. cit.*, p. 89) concludes that the zodiacal light "is the result of the illumination of that portion or section of the earth's atmosphere on which the rays of the sun fall perpendicularly."

§ 3. COMETS.

Thirdly, the COMETS are now known to be simply conglomerations of cosmical dust. These bodies are *not*, as Kant and others have supposed, natives of our system. This is apparent when we consider that their motions, save the fundamental principle of motion in a conic section, bear no conformity to the rule of motions of the planets and satellites. Comets approach the sun from all conceivable directions, moving sometimes nearly in the plane of the ecliptic, sometimes plunging down from the neighborhood of the zenith or rising from the nadir or emerging into visibility in the vicinity of either pole. From a table of 300 comets recently published by Niesten,* it appears that in regard to the inclinations of their orbits 67 ranged between 0 and 30°; 113 between 30° and 60°, and 110 between 60° and 90°. Comets move accordingly in all directions around the sun. About half of all the comets known possess a retrograde motion; though most of the comets of short period possess direct motion — a circumstance which, as will be shown, seems to be due to the perturbative influence of planets moving in a common direction from west to east. That they are foreigners in our system is apparent, also, from the fact that only a small portion of the comets which visit us are known to move in elliptical orbits. That is, the great majority never return to describe another circuit about our sun. They approach from unknown regions, and retire to regions equally unknown. It is further apparent from the non-conformity of comets to the chemical constitution of the sun and planets. We only know that carbon, apparently combined with hydrogen, exists in the substance of some of them. It may be considered, however, very doubtful whether we

*Niesten: *Table des Comètes*, in Annuaire de l'Observatoire Royal de Bruxelles.

are in a position to affirm or deny the presence of any element.

Of the thirty-eight comets, believed to revolve in elliptic orbits, only twelve have been seen at more than one return.

The following is a list of the principal comets of short period. Those marked with a star have been seen at more than one return:

COMETS OF SHORT PERIOD.

		Motion.	Period yrs.
* 1.	Encke's (Pons, 1818)	Direct	3.288
2.	Blanpain's (1819)	Direct	4.81
3.	Burkhardt's * (1766 II)	Direct	5.025
* 4.	Tempel's (1873 II)	Direct	5.066
5.	De Vico's (1844 I)	Direct	5.459
* 6.	Brorsen's (1846 III)	Direct	5.473
* 7.	Winnecke's (1858 II)	Direct	5.727
8.	Pigott's (1783)	Direct	5.888
* 9.	Tempel's (1867 II)	Direct	5.965
* 10.	Swift's (1880 IV)	Direct	?6.
* 11.	Biela's † (Feb. 1826)	Direct	6.619
* 12.	D'Arrest's (June 27, 1851)	Direct	6.664
* 13.	Faye's (Nov. 22, 1843)	Direct	7.412
* 14.	Denning's (F, Oct. 4, 1881)	Direct	8.8567
15.	Peter's (1846 V) ?	Direct	12.85
* 16.	Tuttle's (Jan. 4, 1858)	Direct	13.81
17.	Tempel's (1866 I. "Comet of Nov. Meteors")	Retrograde	33.18
18.	Stephan's (1867 I)	Direct	33.62
19.	Westphal's (July 24, 1852)	Direct	60.03
20.	Pons' (July 20, 1812)	Direct	70.69
21.	De Vico's (1846 III)	Direct	73.25
22.	Olbers' (March 6, 1815)	Direct	74.05
23.	Brorsen's (1847 V)	Direct	74.97
* 24.	Halley's	Retrograde	76.30
25.	(1862 III, "Comet of Aug. Meteors")	Retrograde	? 124.

* Thought perhaps identical with Winnecke's.

† Not seen since 1852. Supposed to have struck the earth at the end of November, 1872, and to have caused the memorable meteoric display at that date. This is Swarm viii of the preceding Table.

It has been conjectured that the great southern comet, I 1880, is the same as the great comet of 1843.* Donati's comet of 1858 has a calculated period of 2,100 years; the comet of 1811 and the great comet, B 1881, periods of 3,000 years; that of 1680 is expected to be absent 8,814 years. Coggia's comet, IV 1874, has, according to Dr. Hepperger, a period of 13,708 years, while the comet of July, 1844, has a calculated period of 100,000 years. These long periods, however, are exceedingly uncertain. The elliptic character, even, of the orbits, is not in all cases fully established. Even when really elliptic, moderate perturbations may cause great change in the periods.

The relative position of the great comet of 1881† is shown in perspective in Figure 5. The point of view is such that the plane of the cometary orbit is presented quite obliquely, and the spectator contemplates it from below. The reader must therefore conceive the lower branch of the orbit much more remote than the upper. P, below the ecliptic, denotes the perihelion point of the comet, and N, the node where it passed from the south to the north side of the ecliptic. This diagram explains why the comet was discovered in May in the southern hemisphere, but was not seen in the northern hemisphere till four weeks later. In May it was below the horizon of northern observers; and later, when it had risen above their horizon, it was too nearly in the direction of the sun to be seen. Meantime it passed its perihelion, and when first seen, June 20, in the northern hemisphere, it was already receding from the earth and the sun. The diagram explains, also, why northern observers saw this comet in the neighborhood of the north star, or the region

* Swift: *Science* i, 258.

† Comet B 1881, discovered by Tebbutt in New South Wales, May 22, and rediscovered in the northern hemisphere, June 20, by G. W. Simmons, then at Morales, Mexico. See an illustrated article *About Comets* by A. N. Skinner in *Popular Science Monthly*, xix, 790–5, Oct., 1881.

toward which the axis of the earth is directed; and why it continued in that neighborhood as it receded during July, though slowly diverging from the direction of the polar star. The diagram also shows why this gradual divergence was to an observer in the evening, toward the left from the pole, in the direction of the sun. This comet remained visible for seven months, and could be faintly seen as late as Christmas, 1881. It was then in the constellation Cepheus. It was even visible telescopically one or two months later. The great comet of 1882 will not be forgotten by the present generation. It was first seen September 2, and continued visible to May 6, 1883, passing over 339½° of heliocentric arc, leaving but 20½° to be completed during the remainder of its orbital circuit, supposing it to be periodic. The great comet of 1680 was visible through 345° of arc, from November 14, 1680 to March 19, 1681.

The great comet, 1882 *b*, just mentioned, is worthy of more particular notice. It was seen at Auckland, N. Z., September 2, 1882; at the Cape of Good Hope, by Finlay, September 6, and at Rio, by Crüls, September 12. In approaching perihelion, it was seen by Finlay and others to pass before the sun's disc, though wholly invisible during the transit. After perihelion, the nucleus was seen to begin to divide, as early as September 28.* On October 5, two nuclear fragments were seen at Strasbourg. Three fragments were reported at the same date by Barnard at Nashville, Tennessee, and Wilson, at Cincinnati; while from Guatemala five distinct bodies were reported.† By October 12, four separate condensations were distinctly seen.‡ On October 14, Mr. E. E. Barnard, of Nashville,

* *Nature*, xxvii, 150, with views for September 16 and October 30. Also *note*, *ibid*, 161.

† *Nature*, xxvii, 113.

‡ W. Doberck, at Markree Observatory. (*Nature*, xxvii, 129, with illustrations.) E. S. Holden saw at Madison, Wis., three condensations (*Amer. Jour. Sci.*, III, xxiv, 435, *Nature*, xxvii, 246).

found, to the south of the comet, "a large distinct cometary mass fully 15′ in diameter, and a similar, but less bright object close behind this, their borders touching, and on the opposite side of the first, a third fainter mass. The three were almost in a line east and west. More of these cometary masses were found toward the south-east. There were at least six or eight within about 6° south by west from the head of the great comet." They were not afterward seen.* Dr. Schmidt, of Athens, had reported a detached cometary mass at an earlier date.† On January 27, Mr. Ainslie Common, of Ealing, "saw the nuclear part of the comet larger but less bright than previously, and resolved into a string of brightish points, the second and third of which were much the brightest." A sketch by Mr. Common showed five points of condensation.‡ The separation of the nucleus seems to have continued as long as the comet remained under observation. These facts are significant, and appear to have an important bearing on the genetic connection of comets and meteors. The calculations of Chandler give this comet an orbit of 4,070 years with retrograde motion. According to Frisby, its period is 794 years; according to Kreutz, 843 years; according to Morrison, 652½ years.§ A. S. Atkinson, of Nelson, N. Z., reports it visible to the naked eye as late as February 28, 1883, and with telescopes, until May 6.‖

Comets generally present a nucleus, a coma of diffused light surrounding the nucleus, and a long tail, generally turned away from the sun, somewhat curved backwards, and having a well-defined anterior border, while the pos-

* *Nature*, xxvii, 400.

† *Astronomische Nachrichten*, No. 2,468, *Nature*, xxvii, 20-1.

‡ *Nature*, xxvii, 400. Something quite similar had been observed Nov. 15.7 by W. C. Winlock at Washington. (*Nature*, xxvii, 129, figure.)

§ *Nature*, xxvii, 300.

‖ *Nature*, xxviii, 225, July 5, 1883. On this comet see the important lecture of Prof. Schiaparelli, reported in *Nature*, xxvii, 533-4.

terior border gradually fades off into space. The tenuity of all parts of the comet is such that stars of the tenth and eleventh magnitudes have been seen, not only through the expanded portion of the tail, but through the most condensed portion, and even through the nucleus itself. From these facts it is apparent that the amount of matter in a comet is generally inconsiderable. This is demonstrated by the fact that the comet of 1776 passed amongst the satellites of Jupiter without causing the slightest disturbance in their motions. The comet, on the contrary, was thrown into a totally different orbit. Similarly, the comet of 1861 actually came into contact with the earth on the 30th of June of that year, and the human race was not annihilated. Indeed, the only indication of the startling event was a peculiar phosphorescence of the atmosphere. According to the accepted relation between comets and periodic meteor showers, it may be said the earth comes in contact with a comet on every occasion of such displays.

In connection with the evidences of the extreme tenuity of comets, may be mentioned the parting of Biela's comet while actually under observation, in 1845. On the 26th of November, it was a faint nebulous spot, not perfectly round, and with an increased central density. On the 19th of December it was more elongated; on the 29th, it had parted. For three months the twin comets were traced with a gradually widening interval between them. Thus they departed from view on their appointed journey of $6\frac{5}{8}$ years. At the end of that period, in August, 1852, the twin comets reappeared, but with an interval increased from 154,000 miles to 1,404,000 miles. The pair were expected again in 1859 and 1866; but since 1852 they have never put in an appearance. Some planet has turned them into an orbit so changed as to be unidentifiable, or their substance has passed into some other condition of exist-

ence. The nucleus of the great comet of 1882 exhibited a distinct tendency to separate into three or four parts. It remained visible till the early months of 1883, still revealing a state of incipient division.

To what other condition of existence is it possible for cometary matter to pass? According to Schiaparelli and Oppolzer, the meteoric ring, or partial ring, is only a degenerated comet. They suppose a train of meteoroids follows in the path of the comet, and that this becomes continually more elongated until the head overtakes it. Comet No. III, of 1862, has an orbit calculated by Oppolzer, which is almost identical with the orbit of the meteoric ring that yields the shooting stars of the 10th of August, as calculated previously by Schiaparelli. This comet then, Schiaparelli concludes, is merely the remains of the original comet out of which the meteoric ring was formed. In other words, the comet and the meteoric ring are one and the same thing. This ring has a major diameter of 10,948 millions of miles; and at the place where the earth traverses it on the 10th of August, it must have a thickness of 385,800 miles, since the meteoric display continues six hours, and the earth travels in August at the rate of 18 miles in a second. The ring reveals itself as a comet only when its nuclear portion happens to be seen near the node when the earth passes. This happens once in about one hundred and twenty years.

By similar calculations, it has been shown that the November meteoric ring, or partial ring, is identical with Tempel's comet, or No. I of 1866. This comet, according to the calculations of Le Verrier, entered our system in the year 126 A.D., passing so near the planet Uranus as to be thrown into an elliptic orbit having a period of thirty-three years.* In consequence of having its perihe-

*This conclusion is rejected by Schiaparelli, in consequence of the alleged insufficiency of the mass. (*Les Mondes*, xiii, 501, March 28, 1867.)

lion at nearly the same point as the earth, it becomes the source of the November meteoric showers, which occur at intervals of thirty-three years.

The lost comet of Biela is thought to reveal itself in a train of meteoroids which was intercepted by the earth November 27, 1872.

As to the physical condition of these cometary groups of cosmical atoms, it appears from spectroscopic observations, that the coma and tail are luminous only by reflected light, like the zodiacal ring; but the nucleus is proved to be self-luminous, either as an incandescent solid or liquid. But it must not be considered as a *continuous* solid or liquid, since its tenuity is far too great. The condition of the nucleus then may be comparable to that of the cloud of heated particles in the flame of a lamp, or that of a mist of molten particles; while the tail may be compared to a cloud of dust illuminated by the rays of the sun.

That some physical relation exists between comets and meteors seems intelligible and entirely probable. The nature of that relation, as generally conceived, is such as has been stated. Undoubtedly the comets revealed to our vision have had a long previous course of development. There seems, at first, reason for supposing that the meteoroidal stage is an earlier rather than a later phase in cometary life. But reflection renders it probable that the regions of cometary evolution lie beyond the limits of a planetary system. In the midst of such a system, the perturbative influences, to which cometary aggregations are so susceptible, must inevitably be of a destructive rather than a constructive character. But I reserve the fuller expression of my own conclusions until after attention has been directed to nebular phenomena, and the collateral indications of a vast stock of world stuff disseminated through infinite space.

§ 4. SATURNIAN RINGS.

Fourthly, the SATURNIAN RINGS afford another example of cosmical dust. These have been shown by Professor Peirce to be neither continuously solid nor liquid. This is also apparent from the inconstancy in the number and aspects of the rings, and the great tenuity of the marginal zone of one of them. The matter of these rings must then be regarded as consisting of particles of solid dust. They have, therefore, the constitution of a comet's tail, and reflect solar light similarly. They are identical with the meteoric rings, save that the constituent particles are more closely crowded, and thus reflect sufficient light to become visible.

It is quite supposable that the zone of the asteroids, of which more than two hundred are now known to attain the size of small planets, is merely another meteoric ring. It is the opinion of some astronomers that the number of asteroids amounts to millions.* This supposition, however, respecting the nature of the asteroidal group is not entertained by the present writer.

§ 5. NEBULÆ.

Fifthly, the NEBULÆ are other and remoter examples of cosmical dust, and are every way full of interest and suggestiveness. These mysterious assemblages of matter demand our most serious attention. They reveal themselves as faint clouds of luminosity lying against the dark blue sky. When Sir William Herschel, with his forty-feet reflector, first brought the nebulæ into prominent notice,† he found that many of them resolved themselves into distinct points of light under the higher powers of his instrument. A nebula, therefore, seemed to be an assemblage

*The 228th asteroid was discovered by Palisa, August 19, 1882.

†It is said that most of his work was done with the twenty-feet reflector.

of thousands of stars, so far removed as to be brought by perspective into apparent close proximity. These he regarded as other firmaments, removed incalculable distances beyond the outer limits of our own firmanent of stars, and having a life probably the counterpart of our own firmamental life. But while thousands of the nebulæ were thus resolvable, other thousands resisted the higher powers of his instrument, which is said to have magnified up to six thousand diameters. The irresolvable nebulæ Sir William Herschel conceived to be crude world-stuff, out of which suns and planets were destined to be made. This idea, so consonant with the previous suggestion of Kant, was taken up by Laplace, and put into the shape of a physical theory, which became known as the "nebular hypothesis." *

With the introduction of the gigantic reflecting telescope of Lord Rosse, fifty-two feet in length, many of the nebulæ were resolved which Sir William Herschel had regarded irresolvable; and many hitherto unseen nebulæ were brought within the range of vision. It appeared, therefore, that the outer limits of the material creation had not been reached, and the suspicion was aroused that all nebulæ might be resolved if we could apply unlimited telescopic power. This idea was antagonistic to the nebular hypothesis, and the latter accordingly receded in favor.

As the power of the telescope to reveal the constitution of the nebulæ seemed to have reached its limit, and the prevailing conviction was only a presumption that all nebulæ are inherently discrete or cluster-like, we are indebted to the spectroscope for any further advance of knowledge in this direction.

* Laplace, however, does not seem to have been acquainted with Kant's older and most suggestive speculations; but he acknowledges his indebtedness to Sir William Herschel, in bringing to light the actual existence of the crude world-material which furnished the starting point of Laplace's speculation. The reader will find a summary of opinions in Part IV of the present work.

The spectroscope, invented by Bunsen and Kirchoff in recent times, is one of the most marvellously efficient instruments for scientific research that has ever been devised. Its powers are magical. It seizes the slender ray admitted to a darkened room through a narrow slit in the window shutter, and extorts from it the confession of the nature of its origin. It compels the ray to write out the names of the substances which enter into the constitution of the luminous body from which it proceeds. It compels it to declare whether its source exists as a luminous gas or vapor, or as an incandescent solid or liquid, or as a glowing solid or liquid shining through gases or vapors. Such revelations of the constitution and physical condition of suns and stars and nebulæ are not alone surprising; they are amazing. A luminous body separated from us by hundreds of millions of miles, sending its light across unexplored intervals of cold space, so remote that the light which falls upon our eyes to-night must have left its source before Shufu reared the great pyramid above the plains of Egypt, has indited a message which we read in the laboratory, like a letter delivered by post from a friend in another city.

And yet this, like other magic, is simple when explained. It all depends on the undulatory origin of light, and the inequality of the waves for the different colors of which white light is composed. Every one understands that a ray of light passed through an angle of a prism is decomposed into seven colors commonly called "primary," which range themselves in a fixed order on a screen. The decomposition of the white ray results from the varying refrangibility of the constituent colors. The different refrangibilities result from the different wave-lengths of different colors. The length of a luminous wave varies from about seven hundred and sixty millionths of a millimeter at the red end of the spectrum to about three hun-

dred and ninety-three millionths of a millimeter at the violet end.* That is, the force which is the cause of the sensation of light produces inconceivably minute undulations in some medium—generally regarded the same as the ethereal medium—and these undulations are propagated at the rate of about one hundred and eighty-five thousand miles a second, entering the eye and striking the retina, and thus being followed by the sensation of light. When the undulations are of such width that only three hundred and ninety-five trillions of them enter the eye in a second, we experience the sensation of red light; when they are so minute that seven hundred and sixty-three trillions enter the eye in a second, we experience the sensation of violet light. Undulations of intervening amplitudes give sensations of other colors of the spectrum between the red and the violet.

Three classes or spectra are to be distinguished. 1. *The Continuous Spectrum;* 2. *The Bright-line Spectrum;* 3. *The Dark-line Spectrum.* If the light proceed from an incandescent solid or liquid, the spectrum is *continuous.* It consists of a series of colors in their fixed succession, gradually shading into each other as we see them in the rainbow. The substance of which the incandescent body is composed does not materially affect the spectrum. Different substances merely give variations in the relative widths of the different colors.

If, however, the light proceed from an incandescent gas or simple substance in the state of vapor, the spectrum consists only of a set of *bright lines.* These occupy different positions, and display, accordingly, different colors of the continuous spectrum. Now the critical fact in spectroscopic science is this: *The bright lines produced by any substance are always in the same relative positions*

*Solar radiations are traceable in greater wave-lengths in the ultra-red, and in shorter wave-lengths in the ultra-violet.

in the spectrum. If we employ a different gas or vapor, we obtain a different set of bright, colored lines. Thus hydrogen gives a broad bright line in the orange, and narrower ones in the greenish-blue and the blue. Sodium vaporized gives a broad line in the yellow, which, with greater dispersive power of the prism-arrangements, becomes a double yellow line. Light proceeding from a mixture of two or more gases or vapors gives the lines characteristic of each. One acquainted with the characteristic lines of different elements is able, on this principle, to indicate what substances are present in the gas or vapor giving a certain succession of bright lines. So constant are the spectroscopic characters of the same substance, and so exact and measurable the phenomena, that our confidence is in no sense abated, even if we know the bright lines are produced by an astronomical body.

If, finally, the light proceed from an incandescent solid or liquid body, and be transmitted through a gas or vapor at a lower temperature, we get a colored spectrum crossed by *dark lines.* And now the critical fact is this: *The dark lines occupy the same relative positions in the spectrum as the bright lines produced by the gas or vapor alone, when incandescent.* In other words, the vapor or gas through which the light is transmitted, absorbs or extinguishes exactly those rays which it is capable itself of emitting. If the vapor alone would produce a yellow line, the vapor transmitting light from an incandescent solid or liquid produces a dark line in the place of the yellow. If incandescent hydrogen produce a bright line in the orange, an atmosphere of hydrogen transmitting light from a solid or liquid body will produce a dark line in exactly the same part of the orange.*

*For a full exposition of the principles, methods and results of spectral analysis, see Schellen: *Spectralanalyse*, translated and republished in America as *Spectrum Analysis in its Application to Terrestrial Substances and the Phys-*

SYNOPTICAL VIEW OF SPECTROSCOPIC PRINCIPLES.

DESIGNATION OF SPECTRUM.		CONDITION OF MATTER.
Continuous Spectrum		Incandescent Solid or Liquid (*Drummond Light*).
Bright-line Spectrum= Discontinuous Spectrum= Direct Spectrum= Gas Spectrum	IMPLIES	Incandescent Gas or Vapor (*Electric Light; Solar Prominences; Irresolvable Nebulæ*).
Dark-line Spectrum= Absorption Spectrum, Reversed * Spectrum or Compound Spectrum	IMPLIES	Incandescent Solid or Liquid shining through gas or vapor of lower temperature (*Sun; Fixed Stars*).

When these principles are applied to the investigation of cosmical light, they reveal the physical conditions of the matter which emits it. For instance, the light of the moon gives the same spectrum as direct sunlight. The same is true of the light reflected from the planets. This, of course, confirms the astronomical doctrine that the planets and satellites shine only by reflected light. If we investigate the light emitted by the tail or the coma of a comet, we find that also to give the same spectrum as sun-light. Hence the tail and coma of a comet are not self-luminous. The nucleus of the comet, however, gives a spectrum of three bright lines. This demonstrates, first, that the nucleus is an incandescent gas or vapor; and secondly, that it contains carbon, since the bright lines correspond to the spectrum of a compound of carbon.

If now, we turn the spectroscope to the nebulæ, we

ical Constitution of the Heavenly Bodies, 1872. Also in abbreviated form, *Half-Hour Recreations in Science*, Nos. 3 and 4, Boston; also Roscoe: *Spectrum Analysis*, Lond., 2d ed., 1870, 8vo. pp. 404. The reader will find important and beautiful applications of the spectroscope in Secchi: *Le Soleil*, 2 vols. and Atlas; and Young: *The Sun*, New York, 1881.

* Quite commonly now, the term "reversed" is applied to *bright* lines appearing, particularly in solar spectra, in the places where *dark* lines usually appear, as, for instance, in the lines due to the deepest part of the solar spots, and in the protuberances. See Young: *The Sun*, 130, 157, which compare with pages 83 and 84. See also Secchi: *Le Soleil*, i, 283-4; ii, 83-98, etc.

discover that almost all those nebulæ which have been *resolved* give spectra identical with the spectra of the sun and the ordinary fixed stars.* This is a grand consummation. It shows that the resolvable nebulæ are possibly what Sir William Herschel conceived them — vast firmaments of suns analogous to that firmament in which our sun is a star. We might picture to ourselves, on the basis of this conception, thousands upon thousands of other firmaments, each with its milky way, its constellations, its variable stars, its countless dark, unseen, but probably habitable planets floating away in immensity, each with its peculiar domestic economy, and each, nevertheless, under the common government of a single empire whose ministers are gravitation, heat, light, ether. Attempting to grasp the conception in its magnitude, we feel ourselves lifted into another realm of being. The limitations of earth and material existence are left behind, and we dwell, gifted with a sort of omnipresence, in the immensity of God's universe.

But what of the *irresolvable* nebulæ? *Their spectra yield only bright lines.* Similar as they are in general aspect, to the resolvable nebulæ, their spectra are fundamentally different. Their physical condition, accordingly, is that of *a glowing gas or vapor.* They are not firmaments of suns. They are incandescent cosmical dust. They are dust so intensely heated that some or all of it is in a state of vaporization. This is another grand consummation. A matured conjecture of Sir William Herschel is confirmed. The world-stuff which Laplace demanded is at hand. Let us see whether the aspects which it presents sustain the idea of progressive world-growth.

Evidences of development seem to be afforded by the *forms* of the nebulæ. Of these we may enumerate the following classes:

* It is impossible to say whether the apparently continuous spectra of some of these nebulæ are crossed or not by dark lines.

1. *Amorphous Nebulæ.*— Here we may include the great nebula in the sword-handle of Orion.* I reproduce for the reader (Figure 6) the careful drawing executed by Trouvelot.† This is one of the brightest of the nebulæ; but at the same time it has resisted all efforts at resolution. Its spectrum, accordingly, consists of a small num-

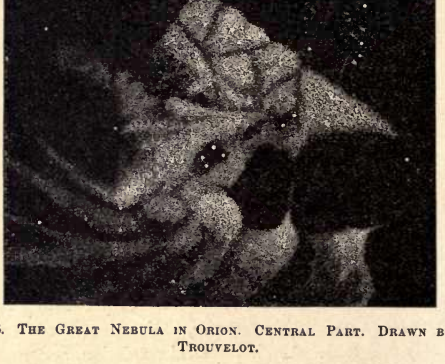

FIG. 6. THE GREAT NEBULA IN ORION. CENTRAL PART. DRAWN BY L. TROUVELOT.

ber of bright lines. Here belong also, the two Magellanic Clouds, visible to the naked eye in the southern hemisphere. I am not aware that their spectrum has been obtained.

2. *Spiral Nebulæ.*—The nebula No. 3,239 Herschel

* Director Otto Strnve classes this among spiral nebulæ (*Monthly Notices, Astronomical Society*, London, 14 March, 1856, xvi, 139; Gautier, *Archives des Sciences Physiques et Naturelles*, Geneva, 1862, translated, *Smithsonian Report*, 1863, 299). It is possibly beginning to pass into the spiral phase. See also Prof. Geo. Bond: *On the Spiral Structure of the great Nebula in Orion*, Monthly Notices, xxii, 203-7.

† Further, on this nebula, see *Nature*, 22 November, 1877, p. 67, and 18 July, 1878, p. 313; Schellen: *Spectral Analysis*, 534.

(Figure 7) presents the form of a sickle or greatly curved tail of a comet. It seems to be an elongated mass of light just beginning a gyration about a centre a little to one side of the head. A remarkable spiral nebula is Herschel 1,173.* But the most striking of all spiral nebulæ is that situated in Canes Venatici (H. 1,622; Figure 8). It is

FIG. 7. SICKLE-SHAPED NEBULA, HERSCHEL 3,239.

impossible to gaze upon these figures without feeling the conviction that a spiral movement is in progress. The spectra of these nebulæ have not been certainly ascertained; but we may venture the conjecture that they will be found to consist of bright lines. Such a spectrum, at least, is given by the spiral nebula H. 4,964, in which lines

*See view in Schellen, *op. cit.*, 538.

answering to nitrogen and hydrogen appear, besides two other bright lines not identified.

FIG. 8. SPIRAL NEBULA IN CANES VENATICI, HERSCHEL 1,622.

3. *Spiro-annular Nebulæ.*—These seem to be undergoing a transition from the spiral to the annular form. H. 604 (Figure 9) is one of these. Another equally transitional is H. 854 (Figure 10), in which we see several segments of spiral or annular forms surrounding a bright nucleus, as in H. 604. The spectra of these nebulæ are also unknown.*

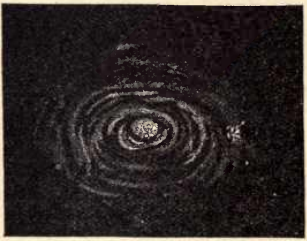

FIG. 9. SPIRO-ANNULAR NEBULA, HERSCHEL 604.

* This, like most of the other nebular types mentioned may be found well figured in Schellen's *Spectral Analysis*, and better in *The Popular Science*

FIG. 10. SPIRO-ANNULAR NEBULA, HERSCHEL 854. INDICATIONS OF SEVERAL RINGS.

4. *Annular Nebulæ.*—A fine example of this form is the annular nebula in the Lyre, H. 4,457 (Figure 11). Its spectrum consists of one bright line answering to nitrogen. The annular nebula is sometimes presented obliquely to view, as in H. 1,909. Sometimes it appears edgewise, as in H. 2,621. At other times it is so attenuated at opposite sides as to be invisible in those places, and appears, accordingly, as a double nebula, as in H. 3,501 and H. 2,552. More powerful instruments may be expected to show the ring complete. In both these cases there is a central mass more or less luminous, as in H. 854, H. 604 and H. 4,447. The nebula, Figure 10, seems likely to

Monthly for June, 1873. Newcomb's *Popular Astronomy* also gives views of The Great Nebula in Orion, the Annular Nebula in the Lyre, the Omega Nebula H. 2,008, the Nebula H. 3,722, and the Looped Nebula H. 2,941. But the most exquisitely delicate representations of nebulæ are found on two plates of Secchi: *Le Soleil*, vol. ii.

FIG. 11. ANNULAR NEBULA IN THE LYRE. FROM A DRAWING BY PROF. HOLDEN.

consist of a central mass surrounded by several rings which may be hereafter more distinctly discerned.

5. *Planetary Nebulæ.*—These are nebulæ with tolerably definite circular outlines, and consist either of a uniform disc, as defined by Herschel, or of a rudely annular or spiral belt surrounding a faint luminosity, which often contains one or more bright nuclei. The bright belt is often fringed by a coma or a bur of light. H. 2,241, as shown in Figure 12, consists of a well defined belt of light surrounded by an irregular coma, but without a nucleus. H. 464 shows a bright ring of the spiral order. It is surrounded by a bur of light, and has two nuclei which scarcely sustain any relations to the general structure. H. 838, Figure 13, has a ring of light consisting of a double band of the spiral order. It is surrounded by a bur of light, and contains two nuclei symmetrically situated, and surrounded each by a dark zone, a luminous haze and a bright ring. The planetary nebula in Aquarius (H. 2,098), consists of a sphere of luminosity surrounded by a fringe of rays. From each side of the sphere projects a protuberance equal in length

FIG. 12. PLANETARY NEBULA, H. 2,241, WITHOUT A NUCLEUS.

to the radius of the sphere. This phenomenon, it has been suggested, may result from edgewise presentation of a ring. This nebula gives a spectrum of three bright lines, one of which is due to hydrogen and one to nitrogen.

FIG. 13.
PLANETARY NEBULA, H. 838, WITH TWO NUCLEI.

6. *Stellar Nebulæ.*—These consist of a bright nucleus more or less resembling a star, which is surrounded by a disc of light, sometimes in alternating bands of brightness. The nebula H. 450 is one of this class, very strongly marked, and it has a spectrum of three bright lines. One cannot help remarking the resemblance to a stellar nebula presented by Donati's comet, on the second of June, 1858. When the central body is sharply defined like a star, the object is known as a "nebulous star."

The six foregoing classes of nebulæ all give, so far as ascertained, spectra of bright lines. They are, therefore, masses of glowing gas. About sixty nebulæ have been investigated by Huggins spectroscopically, with results which are satisfactory for the present. A much larger number were found too faint to yield results which could be relied upon. Of the sixty, about one-third yield spectra of bright lines, and about two-thirds yield spectra apparently continuous. It is an interesting fact that all nebulæ giving bright-line spectra remain completely irresolvable; and all nebulæ which are resolvable give continuous spectra. The "resolvable nebulæ," therefore, do not constitute a class of proper nebulæ. More than half of those forms once regarded as nebulæ must be set down as

starry clusters.* But at least one-third of all so-called nebulæ are real nebulæ—masses of incandescent vapor.

§ 6. UNIVERSAL WORLD-STUFF.

1. *Cosmical Dust.*—The cosmical realm appears, from the survey which we have taken, to be abundantly stocked with the crude material of which worlds are formed. The most familiar substances of our earth are found in meteorites, comets, and irresolvable nebulæ, as well as in resolvable nebulæ, stars and suns. But one system of matter pervades the immense spaces of the visible universe; and it is a dream of physical philosophy that all the recognized chemical elements will one day be found but modifications of a single material element.† When this dream is real-

* Prof. Newcomb, *Popular Astronomy*, p. 444, has given views of two such "clusters."

† It is generally admitted that at excessively high temperatures, matter exists in a state of dissociation—that is, no chemical combination can exist. Now, if the so-called elements are really compounded, a state of dissociation would resolve them into ultimate atoms or molecules, all of one kind. The spectrum of such a substance should be a bright line. If the temperature is such that two or three different molecular arrangements may exist, the spectrum should consist of two or three bright lines. The question may reasonably be raised whether the nebulæ which give two or three bright lines are in such a condition. Dumas, in 1857, based the suggestion of the composite nature of the "elements" on certain relations of atomic weights. (See also *Comptes Rendus*, Nov. 3, 1873.) The conception was maintained in 1866, and subsequently, by Professor G. Hinrichs (*Atomechanik;* also *Amer. Jour. Sci.*, II, xxx, 19, 56, *id.* III, i, 319), from a consideration of the physical properties of the atoms; and further, in 1874, from the relations of atomicity and atomic weights (G. Hinrichs: *The Principles of Chemistry and Molecular Mechanics*, 182. See also, *Amer. Jour. Sci.*, II, xxxii, 350, and *Proc. Amer. Assoc.*, 1869, 112). Berthelot maintains that the atoms of the elements are composed of the same matter, distinguished only by the motions set up in them; and accordingly H. Ste. Claire Deville affirms that "when bodies deemed to be simple combine with one another, they vanish, they are individually annihilated." Dr. E. Haanel has clearly shown that the phenomena of allotropism and combining proportions demand the admission of the complex constitution of the elements (address before the Ontario Association for the Advancement of Education, 1876). Professor Lockyer has published some strikingly confirmatory conclusions based on spectroscopic phenomena (J. N. Lockyer: *Discussion of the Working Hypothesis that the So-called Elements are Compound Bodies*, *Proc. Roy. Soc.*, xxviii, 159, 12 Dec., 1878; *Comptes Rendus*, Nov., 1878; *Amer. Jour. Sci.*, III, xvii, 64,

ized, we shall behold the amazing phenomenon of a universe with its numberless forms, conditions and aspects built out of a single substance.

2. *Elemental Atoms.*—The conception of matter of some sort existing in a highly attenuated state throughout the remote regions of space appears to be as old as the age of Newton. Indeed, the doctrine of the universal diffusion of material stuff in a chaotic period, before the organization of the universe, was a central conception of the Greek atomists, as well as of all those physical speculators who maintained the theory of a *plenum*, down to Descartes.* The doctrine of attenuated matter diffused through the intercosmical spaces of *organized systems* is distinct. Dr. T. S. Hunt has called attention† to some

93–116; *Nature*, xxi, 5; xxii, 4–7, xxiv, 396, Aug. 25, 1881. *Necessity for a New Departure in Spectrum Analysis* (*Nature*, Nov. 6, 1879, *Comptes Rendus*, xcii, 904). But see criticisms on Lockyer's views by H. W. Vogel, *Monatsber. der Berliner Akad. der Wiss.*, 1880, 192 and Nov. 2, 1882, *Nature*, xxvii, 233; also by Liveing and Dewar, *Proc. Roy. Soc.*, 30, 93; *Wied. Beibl.* iv, 366. See also results attained by A. Schuster, *Nature*, xxii, 444. Prof. F. W. Clarke entertains kindred views (*Pop. Sci. Monthly*, ii, 32, Jan. 1873; *Science News*, Feb. 15, 1879, 114). Dr. J. G. Macvicar has also speculated on the assumed identity of the ultimate elements, and their common constitution with the ethereal fluid (*A Sketch of a Philosophy*, Parts I and II, London, 1868); while the late remarkable experiments of Dr. Crooks on so-called "radiant matter" (W. C. Crooks, *Nature*, xxii, 101–4, 125–8, 153–4, *Amer. Jour. Sci.* III, xvii, 281; xviii, 241–62; *Pop. Science Monthly*, xvi, 13–24, 157–67), would seem to be best understood on the hypothesis of the homogeneity of the elements of matter, and the continuity of the states of matter. The ethereal ground of all matter is also maintained by M. Moigno (*Acad. des Sci.*, April 16, 1883, and by Prof. Oliver Lodge (*Nature*, xxvii, 304–6, 328–30, particularly p. 330), whose position is criticised by S. Tolver Preston (*Nature*, xxvii, 579). See also Newton's suggestions given below. The final demonstration seems, therefore, to be impending, and the dream of science is promised a fulfilment. See further on this subject the suggestive lecture of Sir Benjamin Brodie on *Ideal Chemistry*, 1867, reprinted 1880, as also a very accessible paper by Professor F. W. Clarke in *Popular Science Monthly*, No. xlvi, Feb. 1876, 463–71; but more particularly in reference to the cosmical diffusion of dissociated matter, see beyond with the appended references.

* See Part iv of this work.

† Hunt: *Celestial Chemistry from the Time of Newton*, read before the Cambridge Philosophical Society, Nov. 28, 1881, reprinted from its *Proceedings*, *Amer. Jour. Sci.* III, xxiii, 123–33, Feb., 1882. I have depended greatly on Dr. Hunt's suggestions in arranging the historical memoranda which follow.

long-neglected passages in Newton's works, from which it appears that a belief in such universal, intercosmical medium gradually took root in his mind. Newton, as his well known letter to Bentley proves, was persuaded that the power of attraction could not be exerted by matter across a vacuum. These passages show what were his views respecting the nature of the interplanetary medium of communication. Though declaring that "the heavens are void of all sensible matter," he elsewhere excepted "perhaps some very thin vapors, steams and effluvia, arising from the atmospheres of the earth, planets and comets, and from such an exceedingly rare ethereal medium as we have elsewhere described."* The "ethereal medium" referred to here had been suggested in his "Hypothesis," of 1675, where he imagines "an ethereal medium much of the same constitution with air, but far rarer, subtler and more elastic." "But it is not to be supposed that this medium is one uniform matter, but composed partly of the main phlegmatic body of ether, partly of other various ethereal spirits, much after the manner that air is compounded of the phlegmatic body of air intermixed with various vapors and exhalations." He conceives this medium to be in continual movement and interchange. "For nature is a perpetual circulatory worker, generating fluids out of solids, fixed things out of volatile, and volatile out of fixed; subtile out of gross, and gross out of subtile; some things to ascend and make the upper terrestrial juices, rivers and the atmosphere, and by consequence, others to descend for a requital to the former. And as the earth, so perhaps may the sun imbibe this spirit copiously to conserve his shining and keep the planets from receding further from him; and they that will may also suppose that this spirit affords or carries with it thither

* Newton: *Optics*, Bk. III. Query 28, 1704.

the solary fuel and material principle of life, and that the vast ethereal spaces between us and the stars are for a sufficient repository for this food of the sun and planets." Then rising to a still higher generalization, he adds: "Perhaps the whole frame of nature may be nothing but various contextures of some certain ethereal spirits or vapors, condensed, as it were, by precipitation, much after the same manner that vapors are condensed into water or exhalations into grosser substances, though not so easily condensable, and after condensation wrought into various forms; at first by the immediate hand of the Creator, and ever since by the power of nature, which, by virtue of the command 'increase and multiply,' became a complete imitator of the copy set her by the great Protoplast. Thus, perhaps, may all things be originated from ether."

Twelve years later* Newton strengthened this hypothesis by additional considerations. The tails of comets were conceived to afford exhalations which, with progressive rarefaction and dilatation, spread throughout space, and being thus brought under the attraction of the planets, mingle with their atmospheres and contribute support for vegetable life. But since vegetation when decaying passes in part into solid states, while fluids are demanded for the continued sustenance of the vegetable kingdom, the continued supply of these fluids must come from some external source. This supply, he thought, might originate chiefly in the tails of comets.

Still later† he conceived that similar exhalations might proceed from other celestial bodies, for he speaks of the sun and fixed stars as great earths, intensely heated and surrounded with dense atmospheres which, by their weight, condense the exhalations arising from these hot bodies. In succeeding editions he develops the idea of exhalations

* *Principia*, Bk. III, prop. 41, 1st. ed. 1687.
† Newton: *Optics*, 1st. ed., 1704, Query 11.

or vapors proceeding from the sun and other heavenly bodies, and by expansion "through all the heavens," constituting a medium universally diffused. This theory continued to take more definite shape in the mind of Newton till, in the latest editions of the *Principia* and *Optics*, he enunciates the clear conception of a thin interstellary matter "arising from the sun, the fixed stars and the tails of comets, and falling by gravity into the atmospheres of the planets, there becoming condensed and passing gradually, through the influence of gentle heat, into the form of salts, sulphurs (that is, combustible matters), tinctures, slime, mud, clay, sandstones, coral and other terrestrial substances."*

The notion of the existence of a subtile ethereal medium, suggested, as is thought, by passages in the works of Sir Isaac Newton, maintained a place in scientific and philosophic speculations,† but the somewhat different notion of a diffused matter not differing in its substance from ordinary matter, met with almost no response until 1842, when Professor W. R. Grove, in a lecture at the London Institution, propounded the theory that heat and light are affections "of matter itself, and not of a distinct ethereal fluid permeating it;" and he added: "With regard to the planetary spaces, the diminishing periods of comets is a strong argument for the existence of a universally diffused matter; this has the function of resistance, and there appears to be no reason to divest it of the *functions common to all matter.*"‡ In his essay on the *Correlation of the Physical Forces*, published in 1843, he suggested

* Newton: *Principia*, lib. III, prop. xlii.

† See especially Comte: *Philosophie Positive;* Helmholtz: *Interaction of the Natural Forces;* Sir William Thomson: *Density of the Luminiferous Ether*, Trans. Roy. Soc., Edinb., xxi, Pt. i, 1854, Phil. Mag. ix, 36, 1855.

‡ Grove: *Correlation of the Physical Forces*, Youmans' ed., Preface, 6 and 7. The author subsequently states (p. 123) that "the celebrated Leonard Euler had published a somewhat similar theory."

that "worlds or systems" "are gradually changing by atmospheric additions or subtractions, or by accretions or diminutions arising from nebulous substance, *or from meteoric bodies*" (p. 81). His whole essay is grounded on the general doctrine that the so-called "imponderable" agents are nothing but "modes of motion" in ordinary matter excessively attenuated and universally diffused.* In a later edition he suggests that the planetary and stellar atmospheres, expanded through space, are probably in "*a state of equilibrium* with reference to each other," and may "furnish matter for the transmission of the modes of motion, which we call light, heat," etc. In 1866 he still further suggested† that this diffused matter may become a source of solar heat, "inasmuch as the sun may condense gaseous matter as it travels in space, and so heat may be produced.'

Almost simultaneously with Grove, Humboldt‡ placed on record his belief that "exact and corresponding observations indicate the existence and the general distribution of an apparently non-luminous, infinitely divided matter." * * * "Of this impending ethereal and cosmical matter it may be supposed that *it is in motion;* that it gravitates, notwithstanding its original tenuity; that it is condensed in the vicinity of the great mass of the sun; and finally, that it may, for myriads of ages, have been augmented by the vapor emanating from the tails of comets." It is not clear from Humboldt's language that he entertained a conception of diffused common matter, or only of a peculiar fluid, like that insisted on by Dr. Young. What he says is in connection with the assumed ethereal resist-

*See, for instance, pp. 81, 123, 138, 139, 151, 187, 198.

†Address as President of the British Association, 1866.

‡Humboldt: *Kosmos*, Otté translation, Harpers' ed., i, 86. The author tells us in his preface that the work was written for the first time in the years 1843 and 1844, though he had "for many months" previously delivered lectures on the themes embraced, in Paris and Berlin.

ance to the motion of Encke's comet; and, in another passage, speaking of "the vaporous matter of the immeasurable regions of space," he adds, "whether scattered without definite form and limits, it exists as a *cosmical ether*, or is condensed into nebulous spots." His interchanges of terms, however, are similar to those employed by Newton, and it is probable that Humboldt did not imagine any "cosmical ether" having an essential constitution different from that of ordinary matter.

Sir William Thompson in 1854,* in a note on the possible density of the luminiferous ether, expresses the opinion that this substance is "most probably a continuation of our own atmosphere." Sir Benjamin Brodie, on the 3d of May, 1866,† read a memoir in which he advanced the idea that many ultimate chemical elements now only known in combination "may sometimes become, or may in the past have been, *isolated and independent existences*," and on the 6th of June of the following year he pursued the thought further,‡ advancing the suggestion that "in remote ages, the temperature of matter was much higher than it is now, and that these other things (the ideal elements) existed in a state of perfect gas — separate existences — uncombined."

But quite independently, and a few days earlier than Dr. Brodie's last mentioned utterance, very similar views were set forth by Dr. T. S. Hunt. In a lecture on the *Chemistry of the Primeval Earth*,§ he advanced the opinion that the "breaking up of compounds, or dissociation of elements, by intense heat, is a principle of universal application, so that

* Thomson, *Trans. Roy. Soc. Edinb.*, xxi, pt. i; *Phil. Mag.*, ix, 36, 1855.

† Brodie: *Calculus of Chemical Operations*, Proc. Royal Soc., May 3, 1866, *Phil. Trans.*, 1866.

‡ Brodie: *Ideal Chemistry*, a lecture before the Chemical Society of London, June 6, 1867, published in the *Chemical News*, June 14, 1867; republished 1880, in separate form, with a preface.

§ Delivered before the Royal Institution, May 31, 1867, and published in the *Chemical News* of June 21, 1867, and in the *Proceedings of the Royal Institution.*

we may suppose that all the elements which make up the sun, or our planet, would when so intensely heated as to be in the gaseous condition which all matter is capable of assuming, remain uncombined; that is to say, would exist together in the state of chemical elements; whose further dissociation in stellar or nebulous masses may even give us evidence of matter still more elemental than that revealed in the experiments of the laboratory, where we can only conjecture the compound nature of many of the so-called elementary substances." Seven years later, Dr. Hunt * repeated the expression of these views, and added the hypothesis suggested by Sir William Thomson, that our atmosphere and ocean are but portions of the universal medium which, in an attenuated form, fills the interstellary spaces; and added further, that "these same nebulæ and their resulting worlds may be evolved by a process of chemical condensation from the universal atmosphere, to which they would sustain a relation somewhat analogous to that of clouds and rain to the aqueous vapor around us."†

Similar views, in apparent unconsciousness of their suggestion by preceding writers, were put forth in 1870, by Mr. W. Mattieu Williams,‡ who conceived, as Grove had done in 1866, that the sun's heat is maintained by his condensation of attenuated matter everywhere encoun-

*In an address at the grave of Priestley, on *A Century's Progress in Theoretical Chemistry*, delivered at Northumberland, Pa., July 31, 1874; *American Chemist*, v, 46-61; *Pop. Sci. Monthly*, vi, 420.

† See these views reiterated in Preface to his second edition of *Chemical and Geological Essays*, 1878, pp. ix–xix; again at meeting of British Assoc., Dublin, reported in *Nature*, xviii, 475, Aug. 29, 1878; and also before the French Academy of Sciences, published in *Comptes Rendus*, lxxxvii, 452, Sep. 23, 1878; and still further developed in an essay on the *Chemical and Geological Relations of the Atmosphere*, Amer. Jour. Sci., III, xix, 349-63, May, 1880; and finally, in a communication in *Nature*, xxv, 602-3, Apr. 27, 1882.

‡ Williams: *The Fuel of the Sun*. A condensed statement of the contents of this work is contained in *Current Discussions in Science* by the same author in "Humboldt Library," No. 41, Feb. 1883. See, also, Williams on the *Radiometer and its Lessons*, Quar. Jour. Science, Oct. 1876.

tered in his motion through interstellary space. This matter is essentially the attenuated state of the atmosphere surrounding the cosmical bodies. He suggested that this diffused matter or ether which is the recipient of the heat radiations of the universe, is thereby drawn into the depths of the solar mass. Expelling thence the previously condensed and thermally exhausted ether, it becomes compressed and gives up its heat, to be in turn itself driven out in a rarefied and cooled state, and to absorb a fresh supply of heat which he supposes to be in this way taken up by the ether, and again concentrated and redistributed by the suns of the universe (chapter V).

Mr. Williams' suggestion was adopted by Dr. P. Martin Duncan * who, in 1877, also without the knowledge of Grove's priority, but also rejecting Williams' assumption of the equilibrated condition of the atmospheres of the heavenly bodies, conceived the sun to be slowly attracting to itself the earth's atmospheric envelope, and proceeds to deduce from this premise a secular diminution of the earth's climatic warmth.†

There are few investigations the history of which better illustrates the interesting coincidences of conviction in different minds working in complete personal independence of each other. Some recently propounded theory or conjecture, or some scientific stadium reached through the combined efforts of many investigators, seems to set many intellects in a similar mood, in which, by the laws of thought, expectation and attention are turned in one common direction, so that some new conception springs into existence independently in many minds. This principle is still further exemplified in connection with the doc-

* In an address as President of the Geological Society, London, May, 1877.

† The cosmical bearing of the doctrine of dissociation of matter at high temperatures is also implied in the publications of Prof. F. W. Clarke and Mr. Lockyer, previously cited.

trine of disseminated matter in the case of a recent theory which it remains to present. Dr. C. William Siemens in a recent memoir of extraordinary interest, *On the Conservation of Solar Energy*,* catching hold of the suggestions of his predecessors respecting an all-pervading medium, has followed Grove in seeking through its condensation the source of solar heat, though summoning to his aid a mechanism both original and striking. He supposes stellar space "to be filled with highly rarefied gaseous bodies, including hydrogen, oxygen, nitrogen, carbon and their compounds, besides solid materials in the form of dust. This being the case, each planetary body would attract to itself an atmosphere depending for its density upon its relative attractive importance, and it would not seem unreasonable to suppose that the heavier and less diffusible gases would form the staple of these atmospheres, that in fact, they would consist mostly of nitrogen, oxygen and carbonic anhydride, whilst hydrogen and its compounds would predominate in space.† But the planetary system as a whole would exercise an attractive influence upon the gaseous matter diffused through space, and would therefore be surrounded by an interplanetary

* Read at the Royal Society, London, March 2, 1882, and first published in *Nature*, xxv, 440-4, March 9, 1882. See a criticism by E. Douglass Archibald, and Dr. Siemens' reply, in *Nature*, xxv, 504. See also supplementary views by Charles Morris of Philadelphia and Dr. T. S. Hunt of Montreal, together with Dr. Siemens' response, in *Nature*, xxv, 601-3, April 27, 1882; also Prof. S. D. Liveing's notice in address as President of the Chemical Section, British Association, *Nature* xxvi, 404-5, August 24, 1882. This memoir was also published, with some modifications and additions, in *The Nineteenth Century*, May 1882. *The Popular Science Monthly*, June, 1882, in *Annales de Chimie et de Physique*, and other journals.

† On this theory an atmosphere ought to be collected about the moon, of one-sixth the density of the terrestrial atmosphere. That is, the moon should possess an atmosphere capable of producing some discernible refraction. Also Jupiter should possess an atmosphere more conspicuous than that of Mars, in proportion as his effective surface attraction is greater. Dr. T. S. Hunt reminds us that according to Saemann the moon's atmosphere has been absorbed; but then we have to inquire what has prevented renewed condensation about the moon?—even after all pores of the moon have been filled.

atmosphere holding an intermediate position between the planetary atmospheres and the extremely rarefied stellar space."

This conception is supported by the consequences of the molecular theory of gases as laid down by Clerk Maxwell, Clausius and Thomson; since it would be difficult to assign a limit to a gaseous atmosphere in space. Further, it has been directly asserted by various authors from Newton down, as I have already shown; and Dr. Flight, like others before him, has detected in meteoric stones large quantities of occluded carbonic oxyde, hydrogen and nitrogen, with smaller amounts of light carburetted hydrogen or marsh gas, and carbonic anhydride;* all which gases must have been absorbed in distant space, as the time of flight through our atmosphere is too brief, and the heat produced by friction too great. Again, spectrum analysis indicates the presence of gaseous matter in space; and according to the testimony of Dr. Huggins, carbon, hydrogen, nitrogen and probably oxygen exist in cometary nuclei, while, according to the views of Dewar and Liveing, nitrogenous compounds, such as cyanogen, are also present. Dr. Siemens thinks aqueous vapor present in space, though it is not detected in meteoric stones in consequence of the intense heat to which they have been subjected. Captain Abney found benzine and ethyl in the atmosphere at sea-level, and in equal quantities at the altitude of 8,500 feet.†

Applying these conceptions to the problem of solar heat, Dr. Siemens holds that the sun and planets communicate some of their own motion of rotation to the atmospheres condensed about them, and he supposes that in this

* The following are the proportions: CO_2, 0.12; CO, 31.88; H, 45.79; CH_4, 4.55; N, 17.66; Total, 100. Some meteoric stones have been found to contain six times their own volume of these gases.

† *Nature*, xxvi, 586.

way an action like that of a blowing fan is set up, by which the equatorial part of the sun's atmosphere acquires such a velocity as to stream out to a distance beyond the earth's orbit, while an equal quantity of gas is drawn in at the poles to maintain equilibrium. The gases thus driven to a distance in planetary space must, of course, be enormously expanded and highly attenuated, and in this state Dr. Siemens thinks that such of them as are compound may be decomposed by absorbing the solar radiation, and thus the kinetic energy of solar radiation be converted into the potential energy of chemical separation. These dissociated vapors, in consequence of the fan-like action resulting from the rotation of the sun, must eventually be drawn in again at the polar regions. Here, becoming heated both by increased density and by solar emission, they would burst into flame at a point where both their density and temperature should have reached the necessary elevation to induce combustion. The resulting aqueous vapor, carbonic anhydride and carbonic oxide would be drawn toward the equatorial regions, and be there again projected into space by centrifugal force.*

The annexed diagram, accompanying Dr. Siemens' memoir, is described by him as "an ideal corona representing an accumulation of igneous matter upon the solar surfaces, surrounded by disturbed regions pierced by occasional vortices and outbursts of metallic vapors, and culminating in outward streams projecting from the equatorial surfaces into space through many thousands of miles." Dr. Siemens states that an American observer has informed

* The conditions, it will be perceived, are not those of a rotating body surrounded by empty space. In the latter case, the centrifugal force of the sun would need to be increased eighteen thousand times, by a rotary velocity one hundred and thirty-four times as great. But on the postulate of this theory, that all space is filled with similar matter, the gaseous products here considered would be in a state of equilibrium, floating like particles in an atmosphere, so that *any* amount of centrifugal force would suffice to project them away from the rotating body.

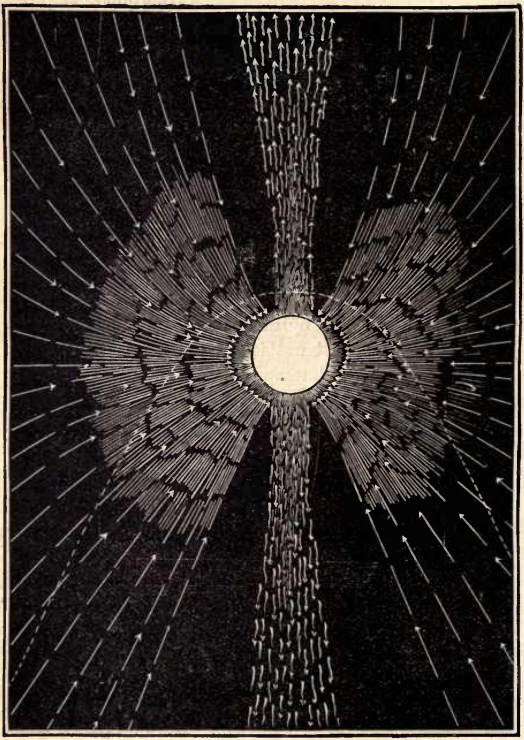

FIG. 14. IDEAL ILLUSTRATION OF THE STREAMS OF OUTFLOWING AND INFLOWING MATTER UPON THE SUN. AFTER SIEMENS.

him that this diagram "bears a very close resemblance to the corona observed in America on the occasion of the total eclipse of the sun on the 11th of January, 1880.

In later communications, Dr. Siemens has suggested other confirmations of his view, specifying the zodiacal light and the spectroscopic researches of Captain Abney, communicated to the British Association in August, 1882, demonstrating the existence of carbon compounds probably analogous to ethyl, and at a low temperature, between the atmosphere of the sun and that of the earth. He refers also to the experiments made by S. P. Langley (with the bolometer), the observations of Professor Schwedoff (yet unpublished), as well as the older observations of R. G. Carrington on the movements of sun-spots.*

Thus, so far, the phenomenon of solar heat is simply one term in the cycle of expansion, dissociation, condensation and recombination, indefinitely repeated. But such a process, even if real, cannot perpetuate solar heat through eternity. It simply delays final refrigeration; since the actual enormous radiation of the sun remains the same, and diminishes daily by a positive amount the aggregate of solar energy to be employed in reproducing solar heat.†

We ought not perhaps, to dismiss Dr. Siemens' theory without stating some physical difficulties which have been charged against it. The following may be mentioned:

(1.) *It would introduce a disturbing mass of matter within the solar system.*‡ The attenuated matter which the theory supposes, would be attracted to the sun and

* Siemens, *Comptes Rendus*, xcv, 771, 1042, Oct. 30 and Nov. 27, 1882.

† For a thoughtful paper touching the general subject of "Matter in Space," see Charles Morris (Philadelphia), in *Nature*, xxvii, 349-51, Feb. 8, 1883. In continuation of the same line of thought, see a paper by A. S. Herschel in *Nature*, xxvii, 458, 504-6.

‡ M. Faye, *Comptes Rendus*, Oct. 9, 1882, p. 612; also Hirn, *Comptes Rendus*, Nov. 6, 1882, p. 812-4.

stars, as M. Faye maintains, and would increase their mass. It would also constitute, disseminated through space, an important hindrance to the motions of the heavenly bodies. A litre of air containing the requisite amount of aqueous vapor weighs at least one gram at ordinary pressure. At a pressure of $\frac{1}{2000}$, which is assumed by Dr. Siemens, this will amount to 0.0005 gram, and a cubic metre will weigh 0.005 kilogram. If we consider the solar system as a sphere which will include the planets as far as Neptune, the weight of the extremely rarefied matter added to the solar system would be 100,000 times the weight of the sun.* Such an addition is physically inadmissible.

The first part of this objection is manifestly disposed of by the state of spatial equilibrium assumed by Dr. Siemens, and which is the express condition of the equatorial outflow, since this is a condition which would prevent the gravitation of the matter toward the sun and stars in any other sense than a possible diminution of tenuity in their neighborhood. This part of the objection does not apply to matter in a state of circulation about centres of attraction.†

The influence of such assumed vapors or gases as a resisting medium upon the motions of the heavenly bodies, has been more especially insisted upon by M.

*The matter added would be, in kilograms, $\frac{4}{3}\pi(6400000 \times 24000 \times 30)^3 \times 0.0005$ kilog.; where the first factor in the parenthesis is the earth's radius in metres, the second is the number of earth-radii in the earth's distance from the sun, and the third is the number of times Neptune's distance from the sun exceeds the earth's. The weight of the sun, similarly, would be $\frac{4}{3}\pi.64000000)^3 \times 5.6 \times 324000$ kilog.; where the first number is the radius of the earth in decimetres, the second the mean density of the earth, and the third the sun's mass relative to the earth. The first of these expressions is 100,000 times as great as the second, and would imply that there exists in the solar system nearly 100,000 times as much matter as has been recognized in the delicate calculations of celestial mechanics.

†Dr. Siemens, in replying to M. Faye's objections, holds that the density of the matter may probably be reduced to one-millionth of one atmosphere. *Comptes Rendus*, 30 Oct. 1882, p. 771.

Hirn.* Referring to Laplace's determination that the total retardation of the earth in its orbit in three thousand years cannot exceed ninety seconds, he states that such retardation would be caused by a gaseous medium of such tenuity that one kilogram should occupy seven hundred billion cubic metres of space, and that even one ten-quadrillionth of a kilogram in a cubic metre (one kilogram in ten quadrillion cubic metres) would suffice to sweep the earth's atmosphere away in a few minutes. To this Dr. Siemens replies by referring to Froude's experiments which seem to show that a solid moving through a perfect fluid would experience no resistance;† and to the experiments of Messrs. Fowler and Walker which demonstrate that the pressure of wind against surfaces is not proportional to their area; from which it is inferred that a planet may move through a rare and highly fluid medium with very little resistance. Moreover, according to the third law of Kepler, a diminution of tangential velocity should lead to a diminution of distance from the centre of attraction, and thus an acceleration of an angular velocity which would neutralize the retardation.

This discussion, it will be noticed, does not particularly concern the existence of small masses and particles somewhat widely scattered in space.

(2.) *The atomic dissociations and associations would neutralize each other.*‡ Granting that the compounds dissociated in space, as Dr. Siemens assumes, by solar and stellar radiations, become recombined on approaching the sun, the recombinations would become dissolved again on attaining the full temperature of the sun's surface, as the sun's heat is believed to hold in a state of dissociation the matters which enter into his constitution. Thus, the

*Hirn, *Comptes Rendus*, xcv, 813-4.
†Siemens, *Comptes Rendus*, xcv, 1040.
‡M. G. A. Hirn, *Comptes Rendus*, Nov. 6, 1882.

heat given out by recombination would be lost by the final decomposition, and the sun would gain nothing.

This is undoubtedly true if the dissociation effected in immediate contact with the sun is as complete as that effected in the interstellar spaces. Dr. Siemens, in replying to M. Hirn's objections,* maintains that such is not the fact, since the sun's photosphere cannot be admitted to possess a temperature above 3000° C. It may be further suggested that dissociation in the sun's photosphere is by no one supposed to proceed further than the disengagement of the elements known to chemistry, while recent science, as I have shown (p. 48), renders probable an ultimate atomic dissolution in other regions of space.

(3.) *The employment of stellar radiations in effecting interstellar dissociation would imply a more rapid diminution of the intensity of light than the law of inverse squares of the distances permits.*† The inherent luminosity of the heavenly bodies must therefore be greater than it appears; but there exists no independent ground for supposing the intensity of light varies materially from the law of inverse squares.

If this conclusion is admitted, it seems to furnish no evidence against the theory. Professor S. P. Langley‡ has shown that a large part of the solar radiations is absorbed by the sun's atmosphere, and another part by the earth's. Indeed it has long been known that the sensible solar intensity is not in accordance with the law of inverse squares of the distances. Moreover, the late experiments of Captain Abney indicate, on independent grounds, the existence of an interplanetary fluid of such nature as the Siemens theory requires. And lastly, M. Janssen has announced as one of the results of his observation of the

* Siemens, *Comptes Rendus*, xcv, 1037–43.

† M. G. A. Hirn, *Comptes Rendus*, Nov. 6, 1882, pp. 812–4.

‡ See especially an important paper in *Amer. Jour. Sci.*, III, xxv, 169–96.

solar eclipse of May, 1883, the "discovery of the Frauenhofer spectrum and the dark lines of the solar spectrum in the corona, showing cosmical matter around the sun." *

Finally, so far as Dr. Siemens' theory of the reproduction of solar heat has any substantial basis, the doctrine of the spatial dissemination of ordinary matter in its elemental or atomic state receives confirmation.

We may now present a conspectus of the principal conceptions entertained respecting the contents of the intercosmical spaces:

Intercosmical space a vacuum - - -	LAPLACE, etc.
Intercosmical space a plenum (Des Cartes, etc.).	
Filled with a peculiar ethereal fluid.	
Common matter not generally diffused -	YOUNG, etc.
Common matter existing as cosmical dust	NORDENSKJÖLD.
Filled only with common matter excessively attenuated.	
Meteoroidal masses not specially important	EULER, GROVE, HUMBOLDT, HUNT, SIEMENS.
Meteoroidal masses performing an important part. - - - - - -	THIS WORK.

§ 7. A COSMICAL SPECULATION.

Hypothesis is the life-blood of investigation.—LOCKYER.

Nil tam difficile est
Quin quærendo investigare possit.—TERENCE.

Now, let us indulge in a cosmical speculation. The universal world-stuff is scattered generally through bound-

* Paris Acad. Sciences, June 18, 1883, *Nature*, xxviii, 205. See the Siemens theory further discussed in *Comptes Rendus*, Jan. 8, 1883, p. 79. Also by W. M. Williams: *Current Discussions in Science*, ch. ii. 1882. Also, recently, by E. H. Cook (*Phil. Mag.*, 400-5, June, 1883. *Amer, Jour. Sci.*, III, xxvi, 67-8, 146) and Dr. Siemens' reply (*Phil. Mag.*, July, 1883. *Amer. Jour. Sci.*, III, xxvi, 146-7, Aug., 1883). Siemens' late lecture at the Royal Institution may be found in *Nature*, xxviii, 19-21. The whole theory, together with the various objections, is discussed in a small volume just published by Dr. Siemens, entitled, *On the Conservation of Solar Energy*, London, 111 pp.

less space. Perhaps, as Macvicar and Saigey* have suggested, this primordial stuff in an extreme state of attenuation, is the ether, the medium whose vibrations, according to Dr. Young, striking the retina, produce the sensation of light. Out of this semi-spiritual substance germinate then the molecules of common matter. It may be but varying modes of the ethereal atom as conceived by Young, which give rise to the sixty or seventy sorts of chemical atoms, whose more complex arrangements constitute the molecules which make up the molar aggregations of ordinary matter. It may be, on the other hand, only a highly attenuated condition of ordinary matter, or matter in a state of ultimate dissociation. This characteristic world-stuff, born out of ether, in the depths of space, or however born, strewn through the depths of space, is acted upon by forces of attraction and probably of repulsion. The material particles, either as atoms, or less probably, as molecules, are drawn by mutual attraction into groups and swarms. Any central attractive force, as of a sun or planet, by causing the particles to move in converging lines, would cause them to become approximated, and ultimately aggregated. Thus, both mutual attractions and centric movements would tend to produce molar aggregations dispersed through space. But in the presence of two or more attractive centres, as in the present constitution of the cosmos, it is impossible that any mass shall fall directly upon its centre of attraction. A body A, Fig. 15, let fall a hundred thousand miles from the earth would not probably fall to the earth. Other attractions besides that of the earth would be felt by it. The resultant of these, the chief of which would be that of the sun and moon, must, in all probability, deflect the body from a straight course toward the earth, as in the direction A F. Scarcely one chance in millions would

*Saigey: *The Unity of Natural Phenomena.* Translation, Boston, 1873.

exist, that the resultant of all the attractions should coincide with the line of descent to the earth. The idea implies, either that all the matter in the universe be arranged along one line coincident with that connecting the body with the earth, or that it be disposed with perfect gravitative symmetry on opposite sides of that line. We must conclude that the falling body would be deflected from its course. A slight deflection would cause it to pass one side of the earth to B, and even to clear the earth's atmosphere. It would then move a hundred thousand miles on the side opposite to that from which it started. But instead of continuing to move in the same direction, the earth's attraction, while it tends to retard the movement along the receding line, B C, Fig. 15, is exerted obliquely to that line, so that after any given interval of time the body is at D′ instead of D, and when its motion away from A is completely neutralized, the body is at C′ instead of C. It is now in the same relative position as when starting from A, but possesses a certain amount of motion in the direction of C C′. As it begins, therefore, to descend toward E, its transverse motion carries it one side of E to D″. But the transverse motion being constant and the descending motion accelerated in consequence of the increasing influence of the earth E, the path described will be a curve. As the transverse motion was generated while the body passed from B to C′, it will be exactly destroyed in passing from C′ to D″. Thus the body will return to A, after having completed the circuit of an elliptic orbit. At

FIG. 15. MOTION OF A BODY IN THE PRESENCE OF TWO OTHER BODIES.

this point it will be in the same relative position as at C' and independently of any external attraction, will proceed to describe an orbit the second time, and thus the process will continue indefinitely. The original deflecting force may indeed continue to act, and other perturbating influences may intervene, and it is readily intelligible that subsequent perturbations may bring the body nearer to the earth, or increase the distance between them. In either case the velocity of the body will be changed. A perturbative influence might even be so adjusted in amount and direction as to bring the body to the earth.

It appears, therefore, that in the actual disposition of the matter of the universe, every body would tend to circulate about every other body. The body whose attractions are most powerfully felt would become the approximate centre of actual orbits for those masses affected by such superior attraction. As the sun is the chief centre of attraction within the solar system, most of the matter within the limits of the system must circulate about the sun. But I see no reason why meteoric matter should not also circulate about the planets and satellites.

The actual conflict of attractive forces is not, however, by any means, as simple as in the case supposed. In spite of the continual tendency of all bodies in space to describe orbital motions about each other, the conflicting attractions are so infinitely diversified in amount and direction, and so variable with the varying distances of bodies, that the very fulfilment of the laws of motion results in a network of movements which is utterly incomprehensible, and must inevitably precipitate countless collisions of particles and masses. The smaller the mass relative to the masses which control its motions, the greater its liability to precipitation.

As to the aggregation of cosmical matter, I have stated that, in addition to the mutual attraction of the molecules,

the convergence of their paths toward centres of attraction must also tend to the formation of masses and swarms of masses and particles. We have then to picture indefinite space as pervaded by swarms of masses and particles of dark matter. Each mass or particle may, nevertheless, be separated by thousands of miles, from its nearest neighbor in the same swarm. I imagine these masses must be continually passing between us and the bright disc of the moon; but each mass is so small relatively, that the light of the moon is not sensibly affected by it. The same is true of any heavenly body presenting a sensible disc, like the planets. But the fixed stars are so remote that, by perspective, they are reduced to points of light. They must be occulted then, by every small mass of dark matter passing between them and us. All small masses within hundreds, and perhaps thousands, of miles of our eyes would probably produce sensible effects upon the light of mere luminous points, unless disguised by the effects of atmospheric refraction. Were there not reasons for supposing the twinkling of the fixed stars a mere atmospheric phenomenon, it might be worth while to consider whether it may not be due to occultations by meteoric matter, especially as the disc-presenting planets are free from scintillation. On this theory, however, a planet so remote as to present no sensible disc should also twinkle to some extent.

Swarms of small masses of dark matter may therefore be conceived as circling in numberless orbits and in all directions about the principal bodies of the solar system, but in much the greatest number about the sun. All the moving bodies of our system must be continually pelted by these cosmical atoms, and the aggregate result of these collisions must, in thousands or millions of years, affect their motions. Supposing the motions of the cosmical atoms to have no prevailing direction, it is evident that

the motions of the planets, satellites and comets of our system would cause them to meet more of these atoms than the total number which would overtake them. The result would therefore be a resistance to the movement of these bodies, and the effect of this would be an acceleration of their motions and a shortening of their periods. I venture the opinion that this cause is a more efficient resistence than the supposed ethereal medium.

This simple conclusion is very fruitful of deductive results,* as Professor M. H. Doolittle has shown. The resistance of an ethereal medium has always been regarded by many physicists as an inadequate explanation of the cometary phenomena which have been appealed to as evincing the existence of a universal ether. But the dense distribution of cosmical matter may fairly be assigned as a physical explanation of the following otherwise perplexing phenomena: 1. The acceleration of all orbital movements, including those of comets, and especially that of the inner satellite of Mars, which revolves about its primary in a little over seven hours, while the planet revolves on its axis in about 24 hours, thus causing this moon to rise in

*It was independently enunciated by the writer in a public lecture, December 3, 1877, at Syracuse, New York. The substance of the lecture was reported in the Syracuse papers of December 4. The lecture was subsequently repeated, December 7, at Groton, New York; January 4, at Pulaski, New York; February 5, at Cleveland, Ohio; February 12, at Richmond, Illinois, and February 16, at Lebanon, Ohio. I find that a similar conception was enunciated at an earlier date, by Rev. S. Parsons, A.M. "No doubt the comets and all other bodies meet with cosmical matter, which is 'diffused profusely throughout the universe,' according to the observation of Laplace. In the course of ages this diffused matter must present a sensible resistance to the motion of bodies through the universe." After citing the abundance of meteoroidal bodies, he added: "Such an amount of resistance would be sufficient to change the earth's orbit from an extreme oval into its present shape" (*Methodist Quarterly Review*, January, 1877, p. 135). The conception was subsequently, though independently, put forth by Mr. M. H. Doolittle, in a paper before the "Philosophical Society" of Washington (New York *Daily Tribune*, March 6, 1878. See a further communication in the same, April 6, 1878)

the west and set in the east.* 2. The irregularities in the motions of comets, especially noted in Encke's; since meteoroids, not being uniformly distributed, would not offer uniform resistances. 3. The want of coincidence between the planes of the equators of the various bodies of the solar system, and between these and the planes of their orbits. This is a group of facts requiring for their explanation the exertion of some force from without the system. 4. The eccentricities of the planetary orbits.

While, however, the phenomena mentioned under the last two heads may possibly be best explained on the hypothesis of meteoroidal resistance, it is admitted that perturbative attractions must probably be cited for the same purpose.†

Returning to the consideration of the constituent masses or particles out of which swarms of cosmic bodies would be constituted, it is manifest that each mass or particle will eventually dispose itself, under the fixed action of the forces of matter, in some definite order. It is manifest also, from what has been said, that each swarm will have a progressive motion along a path having the essential character of an orbit around some dominant centre of attraction. If, as seems to be the fact, an ethereal medium, or any condition of interplanetary matter, exists in space, it opposes the movements of these swarms, by opposing the motion of each constituent mass. But the smaller masses — the particles and molecules — would feel this resistance to the greatest extent. They would therefore fall behind the heavier masses and would be most deflected toward the attracting centre. The smallest particles would be driven farthest to the rear, and dispersed farthest from the orbit of the train, along the side turned toward the

*I shall hereafter show that the solar tidal influence is also adequate to produce such a result.

† These two classes of phenomena are considered in Part II.

principal attraction. The swarm would present an elongated form in which the larger and heavier masses would move foremost, and nearest the line of the orbit—that is, near the exterior skirt of the area covered by the general swarm, as in the case of the bolide at Queengouck (Fig 4)—while the smaller ones would follow, in graduated succession, in a long train which would present a fan-like expansion lying mostly on the inside of the path of the principal masses.

This, it may be conceived, is the mode of aggregation of these cosmical matters in the depths of space. Of course the attractions which control them are feeble; their movements are slow, the resistances are relatively inconsiderable, and the elongation of the swarm is correspondingly inconspicuous. What I have described is a tendency which would be present. Sometimes the controlling attraction would be only another cosmical swarm. The two swarms would revolve similarly about their common centre of gravity; while prolonged resistances would cause their slow approximation and final coalescence at the common centre of gravity. Sometimes the controlling attraction would be exerted by a distant sun, around which it would slowly move, continually gathering up additions of matter from the wide fields of space.

In most cases, all controlling attraction would be feebly felt. These clouds of cosmical dust would float practically poised in the midst of space, and would gradually grow by the continued accession of new matter. Some of them would become aggregates of large dimensions, and their attractions would be distinctly felt by other aggregates. There would be a tendency of such aggregates to approach each other. They might possibly approach along a straight line, but more probably some third aggregation, or some distant sun, would deflect them into orbits about their common centre of gravity, in which, by prolonged collis-

ions of cosmical matter, they are brought to ultimate coalescence with each other. Or some other attractive disturbance affords such a resultant of actions as may bring them more directly together. When these larger aggregations of world-stuff come together, the result is an aggregation approaching the dimensions of the Herschellian nebulæ. To these attention will be directed presently.

There are other aggregations of very moderate magnitude which chance to fall under the influence of some distant sun, toward which they move through a series of ages — deflected, however, by lateral attractions into orbital paths. In the nearer neighborhood of some great attractive centre, the velocity of one of these swarms is accelerated. Its form becomes more elongated. The internal movements of the parts become more vigorous; collisions are sharper, and flashes of light are evolved, and the posterior train is expanded. Further influence exerted by the central body increases all these consequences. The head of the swarm becomes permanently luminous. The long gathering swarm is now a comet. It may have already entered within the precincts of our solar system. It moves toward the neighborhood of our sun with ever-increasing velocity and brilliancy and length of train. Meantime the mysterious power — apparently repulsive — which the sun exerts upon its constituent matter drives off infinitesimal particles, but intensely luminous, to constitute that characteristic appendage known as the tail. This must be distinguished from the train just mentioned. It rushes on; it probably misses collision with the sun, is reined back, and speeds by virtue of its acquired velocity, nearly in the direction of a tangent to the perihelion curve described, into the remoter regions of our system.

When the cometary aggregation comes from an indefinite distance beyond the confines of our system, moved

only by the sun's attraction, it acquires such velocity as to move in a parabolic curve, and hence, when it recedes from the sun it can never return unless its path is changed by some perturbative action. It is extremely improbable that the mass should move with precisely this velocity. The planets of our system, especially when the comet passes in their vicinity, distinctly impress its motions. Sometimes the action is such as to accelerate its velocity, and it then whirls around the sun and departs, never to return, along a hyperbolic path. These non-periodic comets probably proceed across the void which separates our system from neighboring systems. They escape beyond the influence of powerful attractions and correspondingly lay aside their cometary characteristics. Some of them probably unite with other nebular aggregations. Others, escaping through the labyrinth of attractions, move on until another sun calls them to itself. The former experience may then be repeated; and the cometary body may perchance travel from system to system weaving the realm of material existence into a unity.

But the cometary body which ventures into our system may be still differently impressed by the attractions of the planets. Its motion may be retarded. From the moment when its velocity is less than that which it would acquire in falling from an infinite distance, it begins to move in an elliptic path. It is destined to come around again to the same point. It is a periodic comet. Its aphelion is likely to be located near the region where its new path was determined. The largest planets are of course most likely to exert this determinative influence. Hence, of the periodic comets, nearly all have their aphelia near the orbit of some one of the major planets. Thus there is a Jovian group and a Saturnian group. Most of the periodic comets move around the sun in the same direction as the planets; while, of the whole number of comets recorded,

about half have moved in the opposite direction. This circumstance is unexplained, but it must be connected with the direction of the planetary motions, or with a general vortical movement of the ethereal fluid and interplanetary matters, which would exert increased influence on the slackened motion of comets turned into elliptic orbits.

But now, the comet, domiciled within the system, is subjected to constant perturbative torments. Its eccentric orbit carries it across the paths of the planets, and it is pulled successively in various directions. The enormous stress experienced in passing the close vicinity of the sun throws it into a state of violent internal commotion. In a body whose parts are so incoherent, dislocation and disintegration begin. A constituent portion struck by another has its velocity increased, and it tends to move tangentially away from the sun; the part striking has its velocity diminished, and it tends to move nearer the sun. The effect is to disperse the parts. Wrenched and racked by the distracting pulls of the sun and planets, it begins to go to pieces. We have seen comets going to pieces before our eyes. The process may be slow, but it is real and progressive. The train elongates and attenuates, under the influence of the prolonged acceleration of motion experienced on entering our system; and at length the disintegration of the parts proceeds so far that the nucleus loses its luminosity and the swarm of constituents continues for a time to move about the sun as a meteoroidal train. Ever elongating, it may stretch at last quite around its orbit. This extending train, intercepted by planetary atmospheres, rains down its substance in showers of "shooting stars;" but otherwise, it continues gradually to approach the sun, and is ultimately gathered as "solary fuel" in the central fire of our system.*

* The bearing of Von Reichenbach's researches on meteorites and shooting stars ought to have been earlier noticed. He finds all meteoric stones to be compounded of parts — hundreds or even thousands of mechanically separate constit-

The theory which claims a continuity between comets and meteoroidal trains, encounters, it must be confessed,

nents. Ordinary meteoric stones are aggregates of smaller meteoric stones. Both the larger and the smaller are composed of substances whose arrangement always follows a certain order. In the centre are oxidized substances, such as silicates; upon these are layers of sulphurets, graphite, and finally of native iron. If either class of constituents is absent, the remaining ones follow the fixed order. Thus there has been a growth; and the oxides or stony constituents are older than the metallic. So, also, the smaller constituent meteorites are older than the conglomerates formed by their aggregation.

The formation and cementation of the parts has not been effected through the agency of a fusing heat. If so, the heavier iron would not have settled around the lighter olivine, nor would graphite sustain its actual relation to magnetic pyrites. The primitive olivine was surrounded by a primitive iron-gas. The primitive condition of all the substances was gaseous—not nebulous. Under conditions once existing, the oxygen was active and entered into its combinations, forming the primitive stony nuclei of meteorites. Later, the sulphides, and then the graphite, were isolated and deposited. Finally, either because the oxygen was exhausted or inactive, or because the work was carried on in a different laboratory, the unoxidized iron was deposited in layers and fillings of all the interstices. All these layers are crystalline.

Thus, before the existence of the meteorites which fall from heaven in our time, there must have been a certain period in which smaller, finer, and more numerous meteorites (*Meteoritchen*) were produced—as "mere dust, starch-flour, sand, grains to the size of hail-stones"—these in their microscopic structure composed of still minuter bodies.

Shooting-stars and fire-balls are only meteoric bodies, so small as to be dissipated in our atmosphere on their way to the earth. These bodies, large and small, float in space, and by degrees are drawn to the earth. In the course of ages they must contribute important additions to the earth. Nickel and cobalt, he explains, are found in all our soils. They are not afforded by the rocks from which soils are chiefly formed; but they are characteristic constituents of meteorites.

The constituent parts of meteorites present evidence of collision and attrition. They are rounded, as well as angular and subangular. The very dust worn from them (*Reibsel*) is cemented together with the larger kernels and balls by means of nickelliferous iron. When ignited in our atmosphere, they are again dissipated in vapor. "Und man hätte sich dieses als einen feinen Regen, als einen unsichtbaren Duft zu denken, der in äusserst geringer Menge und in höchst feiner Vertheilung ohne Unterlass sich aus der Atmosphäre auf unsere Meere, Wälder und Gefilde niedersenkt."

It is at once apparent how the facts here cited quadrate with the theory set forth in the text.

These speculations of Von Reichenbach are embraced in a series of memoirs as follows: *Ueber die Zeitfolge und die Bildungsweise der näheren Bestandtheile der Meteoriten*, Poggendorff's Annalen, cviii, 452–65, 1859; *Meteoriten in Meteoriten*, id., cxi, 353–86, 1860; *Meteoriten und Sternschnuppen*, id., cxi, 387–401, 1860; *Die Sternschnuppen in ihren Beziehungen zur Erdoberflächen*, id. cxxiii, 368–74, 1864.

some difficulties not yet fully explained. The common representation is that the train of the meteoroidal swarm is to be identified with the tail of the comet; but this is evidently inadmissible, because the comet's tail precedes during the retreat from the sun, and because the velocity implied in the distant parts of the tail while passing perihelion is entirely inadmissible as an actual translation of matter, and perhaps also, in consequence of its considerable luminosity at great distances from the sun. Again, the luminosity of the head itself, at a distance as great as Mars or Jupiter from the sun, cannot be due to the intense heat of the sun's rays, as might be the case at perihelion. The amount of collision among the parts, in an aggregation containing so little matter as a comet, can with difficulty be conceived as imparting the permanent luminosity; and the query arises whether the phenomenon is not due to some other action than heat. It is supposable that the light of the tail is wholly reflected, as we know most of it is, in the nearer vicinity of the sun. The nuclei are well known to contain incandescent gases when they have been examined on their visit to the sun's neighborhood; but one would expect masses so limited in amount to lose their thermal luminosity in receding toward their aphelia.*

The phenomena of the tail, especially in the vicinity of aphelion, are such as would result if we could conceive the nucleus of the comet surrounded by an aura extending on all sides as far as the remotest limits of the tail, and could recognize the tail as merely a *luminous shadow* cast by the nucleus in intercepting certain radiant energy proceeding

* One is reminded, in this connection, of the analogies between cometary tails, the streamers of the *aurora borealis* and the trains of radiant matter in the tubes employed by Professor Crookes (see references, p. 49). Without affirming a "fourth state of matter," or even the doctrine of the continuity of states, it is apparent that the attenuation of the medium in which the phenomena of "radiant matter" are revealed, is quite analogous to that of the medium in which the northern streamers dance, or in which the tails of comets execute motions of such mysterious velocity.

from the sun.* Perhaps, after all, the theory is the most plausible one which contemplates the tail as a vapor of some unknown constitution, perpetually driven off by some mysterious repulsive power of the sun, perhaps electric, growing more intense with diminished distance. The tail would be, therefore, not a material form moving with the comet, but something perpetually renewed, while the older and more distant emanations disappear from visibility. M. Faye, in this view, compares the comet's tail to the smoke rising from the pipe of a transatlantic steamer, which, though continually changing molecularly, is the same phenomenon all the way from Havre to New York.

Thus we glimpse in outline the cosmic conception which forms the ground of the reasonings and speculations of the present work. The world in which we live is to be accounted for, and the method of its evolution explained. Geology undertakes to write some chapters of its past history; but a true geology, in a broader sense, will unfold many other glowing chapters, which mere inductive science could never make known. We take up the details of the first chapters of inductive geology with the feeling that much has been left out. They present only the beginning of the last act of the drama. But our intelligence presses back in search of a real beginning of the world; and even if scientific inquiry is doomed to failure in its search for an absolute beginning, it is a noble impulse and an inalienable prerogative which sanction the effort to press as far as possible toward the absolute beginning. I doubt if we can at present fix upon a starting point antecedent to that diffused chaotic condition of world-stuff of which so many glimpses have been revealed to the mind's eye. I strongly believe we have

* See W. A. Norton on comets in *Amer. Jour. Sci.*, II, xxvii, 86, 103; xxix, 79, 383-6. See also Bredechin's researches on the tails of comets, *Annales de l'Observatoire de Moscou*, vols. iii-vi, and M. Faye's memoirs, *Comptes Rendus*, Aug. 1 and 8, 1881.

caught glimpses of the mode of formation of world germs. It remains then, to trace their development, their maturity and their decadence. This will lead us to the study of nebular life, and the nature of the continuity existing between nebulæ, suns and planets; and to contemplate finally those ulterior planetary conditions which disclose the data of a geology of the future, and complete the natural cycle of cosmic existence.

CHAPTER II.

NEBULAR LIFE.

Que dire de ces espaces immenses et des astres qui les remplissent? Que penser de ces étoiles qui sont sans doute, comme notre Soleil, des centres de lumière, de chaleur et d'activité, destinés comme lui, à entretenir la vie d'une foule de créatures de toute espèce?—Le padre SECCHI.

THE irresolvable nebulæ, as I have endeavored to indicate, are probably nothing but stupendous examples of meteoric or cosmical clouds which have become heated to such an intensity that their matter, or some of it, exists as vapor, though it is not necessary to suppose that the portions subjected to observation sustain a temperature of relatively high intensity. At the same time, such is their enormous mass that their interiors must be compressed to many thousand times the density of the exterior portions. These prodigious accumulations may have been gathered, by the mutual attractions of the parts, from wide contiguous fields of space. They are not drawn out into meteoric rings or partial rings surrounding our sun, because they are so immensely remote as to be little affected by the solar attraction, and are relatively so vast as to possess controlling power of their own. They have not formed meteoric rings around other suns, because they are equally remote from them and equally exceed them in mass. According to the conception from which we reason, the nebular aggregations discernible within our field of vision—both resolvable and irresolvable—lie dispersed through unlimited space. Many—perhaps most or even all of them—float within the bounds of that starry universe whose nearer members constitute our vis-

ible firmament. But if with Herschel we set limits to our starry firmament, we may readily believe that many of these nebular aggregations lie far beyond the distance of its remotest star. According to Father Secchi, the depths of the cosmos are unfathomable. All the stars constituting the firmament surrounding our sun are but a patch of the boundless Milky Way, and if seen from a certain distance would appear only as a white spot in the Milky Way itself. In any view of the relative positions of the nebulæ, the cosmic organisms of infinite space lie separated by such enormous intervals that while one of these clouds of world-stuff must feebly feel the attractions of other material masses, it may be regarded as practically removed from their influence. We have now to inquire, what will be its behavior?

§ 1. NEBULAR HEAT.

1. *Heat Produced by Refrigerative Contraction.*—At an earlier period, we must assume, the gathering nebulous matter was cold and non-luminous. Accordingly we may conjecture that countless germs of future nebulæ exist in space, which have not yet been discovered, because not yet heated. By what means a nebulous mass becomes so heated as to be self-luminous, is supposed by some physicists to be demonstrated by the uniform evolution of heat in every body which undergoes condensation by pressure. Helmholz, Peirce, Sir William Thomson and others have calculated the amount of heat which must be evolved during the condensation of the sun from such a volume as would fill the orbit of Neptune.* Young and others have suggested that the heat of the incandescent nebula whose

*Mr. Maxwell Hall has calculated that to supply the sun's loss of heat from radiation, it is only necessary to contract 39.15 metres a year. This would require 18,263 years to effect a shrinkage of one second in the sun's diameter (*Monthly Notices, Astronomical Society*, 1874, 237).

condition is revealed by the spectroscope, has been liberated during a process of spontaneous condensation. If this explanation is legitimate and sufficient, it is unnecessary to seek farther for the cause of nebular luminosity.

The explanation, however, seems to be a suitable subject for examination. At first glance it would seem to contradict reason. It is quite apparent that if the nebula is internally in equilibrio, such heat would be evolved if the condensation were effected by the application of force *from without* — as the air is heated in a condensing syringe, or iron under a hammer. But a *spontaneous* condensation excludes the application of extraneous force. It means a condensation under the influence of forces resident in the mass. These forces as far as this question is concerned, are central attraction, molecular attractions and repulsions, and heat. At a given moment, in a nebula internally in equilibrium, the central attraction of the parts is exactly balanced by the repulsive or expansive force due to the amount of heat belonging to the body. Without any change in the relative intensities of these shrinkage and expansive forces, the volume of the nebula must necessarily remain unchanged. Its temperature, of course, remains unchanged. If, at any moment, its temperature is above that of surrounding space, it must radiate a portion of its heat. A certain amount of contraction exactly corresponding with the amount of heat lost, will ensue. The equilibrium between the reactionary and the central attractive forces is restored, and the volume must remain unchanged until farther loss of heat takes place. Thus, the condensation, supposing always that the aggregative process is completed, can only respond to loss of heat. No condensation can take place except as a consequence of such loss. The condensation, therefore, *cannot increase the heat.* If, during a process of condensation, the temperature is raised, this, in the light of the princi-

ples stated, must be the consequence of force applied from without.

Obviously, there is a period in the aggregation of a nebula during which the central attraction may be regarded as crowding the constituents together; and during this period, heat would be developed. An equilibrium being attained between this attraction and the repulsive forces, the nebula will have reached the normal state at which its evolutions begin. Some nebulæ, undoubtedly, exist in the prenormal state, and may be growing heated by condensation — but it has not seemed to me that all nebulæ must be supposed in this condition. Perhaps the greater number must be in some stage in which the condensation is conditioned and measured by the cooling.

Professor Simon Newcomb in his admirable work on "Popular Astronomy" (pp. 507, 508), speaking of the possible cause of the perpetuation of the sun's heat, says: "As his globe *cools off* it must contract, and the heat *generated by this contraction* will suffice to make up almost the entire loss." That is, cooling causes contraction, and contraction causes heat; therefore *cooling causes heat.* But further: "By losing heat a gaseous body contracts, and the heat generated by the contraction exceeds that which it had to lose in order to produce the contraction."* This curious paradox was rendered rational by a learned investigation published by Mr. J. Homer Lane, of Washington,† the gist of whose paper is thus summarized by Professor Newcomb: "If a globular gaseous mass is condensed to one-half its primitive diameter, the central attraction upon any part of its mass will be increased fourfold, while the surface upon which this attraction is exer-

* Then certainly the body is growing hotter and consequently expanding while it contracts from cooling!—unless, meantime, the surplus heat is lost by radiation.

† *American Journal of Science* for July, 1870.

cised will be reduced to one-fourth. Hence the pressure per unit of surface will be increased sixteen times, while the density will be increased only eight times. Hence if the elastic and gravitating forces were in equilibrium in the primitive condition of the gaseous mass, its temperature must be doubled in order that they may still be in equilibrium when the diameter is reduced one-half."

For the sake of further elucidating this curious paradox let us enunciate the points in the following form:

(1.) If the diameter is reduced one-half, the density is eight times as great, since the same matter is compressed into one-eighth the volume.

(2.) The intensity of attraction, and therefore the total attraction, at the new surface, is four times as great, since the same amount of matter attracts at one-half the former distance from the centre of gravity.

(3.) But the new surface is only one-fourth the original surface; hence each unit of new surface must receive sixteen times the attraction (pressure) of a unit of the original surface.

(4.) If the pressure is sixteen times as great, and the density is only eight times as great, the elastic force to equilibrate the excess of pressure must be twice as great.

Now, *if that elastic force is wholly heat*, the shrunken body must have twice the heat of the original body; and that is what the contractional theory, as commonly stated, concludes; and in this way a surplus of heat may be radiated, and still a constant or even increasing temperature maintained.

But the new body has not twice the heat of the old body, since, necessarily, a constant radiation of heat has been taking place.

If, by hypothesis, the original body has shrunken to half its dimensions, and by observation, some of its heat is known to have been lost, the new body will be half the

diameter of the old, without having twice the amount of heat. That is, *the elastic force which equilibrates the excess of pressure is in part at least, something besides heat.*

This is also evident from the consideration that the body is supposed to shrink simply in consequence of cooling; and the supposition of an increase of heat is in conflict with the assumed premise. A body cannot be growing hotter in consequence of a shrinkage produced by growing colder. It may have some of its heat restored, and thus its cooling retarded. To assume that the temperature is not lowered in correspondence with a decrease of volume when the pressure is constant, is in conflict with the well established law of Charles.

But it is assumed that the heat developed by shrinkage is lost through radiation in the meantime. If only the excess developed is lost, the body remains of the same temperature as at first, and, therefore, is not cooling, as the premise demands.

Also, if the excess, or more than the excess of heat is radiated, then there is *less* elastic force in the form of heat than in the original body, while the reasoning requires twice as much.

It seems, therefore, that the doubled elastic force required in the shrunken body to equilibrate the increased pressure must be something besides heat. May it not be simply a repulsion among the molecules, which varies according to some law of the distance?

Now, the following seems to me to be a correct summary statement of the whole case:

(1.) The falling together of the particles and masses will generate heat; and the generation will progress as long as the parts continue to descend toward the common centre of gravity.

(2.) The heat thus developed will be active, sensible

heat. The sensible temperature resulting must, however, be discriminated, as always, from the total thermal potency in the body.

(3.) The centric movement of the parts will cease when the elastic forces become equal to the gravitating tendency of the parts. The nebula is then, disregarding the effect of progressive radiation, in a state of internal equilibrium.

(4.) Subsequent loss of heat will permit the parts again to fall together, until their approximation, or in other words, the work done by the descending parts, develops an increased amount of elastic force, partly heat, which will again equilibrate gravity even at its now increased intensity.

(5.) The loss of heat diminishes the total amount of heat, and diminishes the temperature; but the descent of the parts will necessarily develop a new amount of heat, and partially restore the temperature and volume.

(6.) The former temperature cannot be completely restored, for that was a temperature which maintained the mass at the volume which it had before the contraction; and by hypothesis, contraction is a fact.

(7.) As the newly developed heat must fail to equilibrate the newly increased pressure, the equilibrium must be completed by some reactionary force which would exist at absolute zero of temperature.

(8.) The actual volume will lie, therefore, between the original volume and that which would have resulted if contraction had not developed heat; and the actual temperature will lie between the original temperature and that which would have resulted if no heat had been developed by contraction.

(9.) It is true, then, that contraction develops heat, and that its development delays final refrigeration;—that is, the progress toward final refrigeration is not as rapid as the amount of radiated heat implies. But it is not true

that contraction (from cooling) can have developed the whole amount of heat at any time existing in the mass, or can even maintain a body at a constant temperature.

2. *Changes in the Forms of Nebulæ.* — From this quite abstruse question let us return. If we have to conclude that a shrinkage or condensation in a gaseous mass whose parts are maintained in a state of mutual equilibrium is physically incapable of developing the heat which we find existent in nebulæ, then we have to inquire, what is the *external* cause which develops, maintains or increases the heat of a nebulous mass in space?

As I have stated, we may reasonably assume the cosmical dust promiscuously distributed. But mutual attractions would, sooner or later, result in conglomerations of relatively moderate size. This process would be accompanied by a transformation of gravitational energy into thermal, and this would be continued until the internal elastic forces should be able to equilibrate the gravitational forces. The nebula would have assumed its normal condition. Every nebulous conglomeration would still be attracted by any other—both the larger and the smaller. The process of conglomeration would, therefore, tend to continue indefinitely. Those immense nebulæ would finally be developed which have attracted the attention of astronomers. The larger masses having drawn to themselves all the smaller masses in their several regions of space, the intervening spaces would seem to be comparatively free from nebulous matter.

Now, I would suggest that the process of conglomeration may explain the *irregularities in the forms* of certain nebulæ. The protuberant portions, the salient angles, the denser bands, the luminous spots, may all be conceived as precipitated nebulous masses which have not yet had time to become completely coalesced; or they are nebulous masses which have been pushed out of symmetry or homo-

geneity by the impact of a foreign mass. We have gazed on those irregular forms, like the nebula in Orion, and the Magellanic Clouds, and, mindful of the law of matter by which, when free to move upon itself, it assumes the spherical form, we have deemed it mysterious that such irregularity could persist. Now, on the theory just enunciated, the irregularity must arise; but there is nothing to cause it to persist. The irregular nebula *must* be in process of assuming some symmetrical shape. Its destined shape is not already assumed, because the history of its evolutions began in finite time. The nebula *has not yet had time sufficient* to undergo its changes. Its destined evolution must, therefore, be in progress at this moment. Now, it is gratifying to be able to announce that changes have been noted in nebular phenomena. "Some nebulæ have vanished; others have appeared where formerly no nebulosity had been recognized." Not a few changes have been witnessed in the *forms* of nebulæ. The Magellanic Clouds, according to Sir William Herschel,* have undergone important changes during a human lifetime. The great Nebula in Orion (Figure 6) is now generally admitted to be in process of change.† The nebula surrounding the remarkable variable star Eta Argus is subject to great changes.‡ The Omega Nebula (H. 2,008) through the careful researches of Professor E. S. Holden, is shown to be probably undergoing internal changes.§ The various

* Herschel, *Phil. Trans*, 1811. So, also, Sir John Herschel: "Speaking from my own impressions, I should say that in the structure of the Magellanic Clouds it is really difficult not to believe we see distinct evidence of the exercise of such a power of aggregation."—*Address, British Association*, 1845.

† Schellen: *Spectral Analysis*, 371; Sir W. Herschel, *Phil. Trans.*, 1811; Otto Struve, *Monthly Notices Astronom. Soc.*, London, March 14, 1856, vol. xvi, p. 139; Gautier, *Archives des Sciences Physiques et Naturelles de Genève*. 1862, translated in *Smithsonian Report*, 1863, 299; Secchi, *Comptes Rendus*, lxv, p. 643, lxvi, 63.

‡ F. Abbot, *Proc. Roy. Astron. Soc.*, Nov. 13, 1863; *Am. Jour. Sci.*, II, xxxvii, 294-6.

§ Holden: *On Supposed Changes in Nebula M.* 17, *Am. Jour. Sci.*, III, xi, 341-61, May, 1876.

drawings of this nebula, from that of Herschel in 1833 to that of Lasell in 1862 (Fig. 16), and that of Trouvelot and Holden in 1875 (Fig. 17), seem to indicate that the eastern or omega-shaped portion of the nebula has undergone considerable change in respect to the stars in closest

FIG. 16.—THE OMEGA NEBULA. FROM A DRAWING BY LASELL IN 1862.

contiguity to it. Professor Holden says: "These drawings show that the western end of this nebula has moved relatively to its contained stars from 1833 to 1862, and again from 1862 to 1875, and always in the same direction." Meantime the conspicuous "streak" or wing extended toward the east has not moved in reference to the

FIG. 17. THE OMEGA NEBULA. From a drawing by Trouvelot and Holden in 1875.

stars. The parts of this nebula are, therefore, in motion with reference to each other. The Trifid Nebula has been shown by the same investigator * to possess a proper motion in reference to the stars. This nebula consists of three nebulosities separated by dark passages, as shown in Fig. 18. In the middle of the intervening space, from

FIG. 18.—THE TRIFID NEBULA.
FROM A DRAWING BY TROUVELOT.

1784 to 1833, was situated a distinct triple star; but "from 1839 to 1877 the triple star was not centrally situated between the three nebulosities," but involved in one of them.†

* E. S. Holden, *Am. Jour. Sci.*, III, xiv, 433-58.

† On the motion of nebulæ in the line of sight, see W. Huggins, *Proc. Royal Soc.*, March, 1874. Seven nebulæ observed indicate a motion in reference to the earth ranging from one to fourteen miles a second.

We may rest assured that fleecy masses like the nebulæ, when presenting forms as unsymmetrical as some of them, cannot be reposing in a state of finality.* We may wonder that these changes should be so slow that the nebula seems almost in a fixed condition. That apparent slowness of change, we may be certain, is a consequence of the inconceivable remoteness of those bodies. The star known as 1830 Groombridge is moving through our firmament at the rate of 200 miles a second; yet it requires 123 years to move over an angular space equal to the diameter of the moon. The diameters of some visible nebulæ are probably greater than the distance which separates us from the nearest star. Motion in masses so immense and so remote must necessarily seem deliberate. The earth takes twenty-four hours to turn over; the sun requires twenty-five days; a flea needs but a small fraction of a second. The moon revolves around its orbit in twenty-seven days, but Uranus consumes the time of three generations of men. Yet the diameter of the orbit of Uranus may easily be less than the space separating two distinguishable points of star-dust in a resolvable nebula. I think, therefore, we are not stretching the physical probabilities in attributing the irregularities of the nebulæ to the process of conglomeration; and in anticipating that the shapeless nebula in Orion will one day have assumed a symmetrical form.

3. *Heat Arising from the Aggregative Process.*—The thought must already have suggested itself to the reader that the process of conglomeration affords an explanation

* For mention of other supposed changes, see the memoir of Gantier, already cited. On the general question of nebular changes see Arago: *Astronomie populaire.* In some instances changes of brightness have been observed which are far more striking than any observed changes of form. The small nebula in Taurus, discovered by Hind in 1852, had disappeared in 1861, and was not again visible till 1868, after which it again disappeared. So conversely, the temporary star discovered by Dr. Schmidt in the Swan, gradually faded into the appearance of a planetary nebula.

of the intense heat which vaporizes its substance, and causes it to yield a spectrum of bright lines. As the sudden compression of a portion of atmospheric air yields heat sufficient to ignite tinder, or fuse and volatilize a descending meteor-mass, so the precipitation of one planet upon another would liberate sufficient heat to reduce them both to a state of fusion, or even of vapor. Still more must the intensest heat be generated by the impact of two nebulous masses, one, or both of which together, may embrace more matter than all our planets and the sun combined — as much even as the matter of our entire visible firmament of stars.* One experiences a distinct feeling of relief in the discovery of such a possible means of ignition of nebulæ. Our first discovery of nebulæ disclosed them existing already at an intense temperature. Again and again the question has been raised, "Whence the heat?" We could only reply, "That is a mystery. The incandescent condition may be primordial. Who knows but matter may be created incandescent?" Such answers and such suggestions have been offered. Now, in accordance with the theory of nebular conglomeration, we may, if we please, recognize the *possibility* of the creation — or at least, the normal existence — of matter in *any* assignable state; but we have grounds for tracing nebular history one step farther back. We must conceive of dark nebulæ that have not yet been pounded into a white heat. We must conceive of nebulous particles now first marshalling raw recruits of matter into a forming phalanx. Even yet, the mystery of beginnings hangs over us. We have not

* These sentences were written before the arrival of *Nature* of January 10, 1878, where a communication of James Croll sets forth an identical suggestion. On the heat generated by the impact of cosmical bodies see also Croll: *Climate and Time*, p. 353. Two bodies each half the mass of the sun moving directly toward each other with the velocity of 476 miles a second, would by their concussion generate in a single moment heat sufficient to last 50,000,000 years at the present rate of solar radiation.

yet seen molecules rolling themselves up into visibility. We have never, even in imagination, seen atoms emerging from the dread abyss of nothingness. Let us explain all we may; let us seek out all antecedent conditions possible, enough will still remain to pique our curiosity, and awe us by its mystery. Nay, the farther we trace the links of the chain of causation, the more palpably we feel the need of some support which is *not* one of the links in the chain, but is superior to the principle of finite causation, and is self-sufficient, existing out of relation to succession, time and space.

§ 2. NEBULAR ROTATION.

1. *Causes of Rotation.*— It thus appears that the hypothesis of nebular conglomeration explains two otherwise inexplicable phenomena — nebular amorphism and nebular heat. A *third* phenomenon, hitherto mysterious and unexplained, is equally accounted for. That is, the *rotary motion* which sometimes arises in nebulous masses. This difficulty has often balked belief in the nebular theory of the origin of the solar system.* The moment, however, that we recognize the probability of the collision of nebular masses, the idea of rotation necessarily arises. A nebular mass comparatively minute, impinging upon a mass of any dimensions, would inevitably generate a rotation, in every case except when the centres of gravity of the two masses moved toward the same point, and (unless moving in the same staight line) with such velocities as to reach it at the same instant. This is a case which is im-

* Rev. W. B. Slaughter says: "It is to be regretted that the advocates of this [nebular] theory have not entered more largely into the discussion of it [the origin of rotary motion]. No one condescends to give us the rationale of it. How does the process of cooling and contracting the mass impart to it a rotary motion?" (*The Modern Genesis*, p. 48.) Even Helmholtz says the rotation "must be assumed." (*Interaction of Natural Forces*, Youman's ed., 231; *Popular Scientific Lectures*, 175.)

possible in the ratio of millions to one. I have heretofore stated that when the two bodies consist of matter as dense as the earth and a cold meteorite descending from a distance of a hundred thousand miles, the small body would probably be so much deflected by lateral attractions as to miss the large one, and would, consequently, begin to revolve about it in an orbit more or less elliptical. With masses of matter as voluminous as nebulæ, such orbital revolutions must sometimes be established; but it is very apparent that the collision is vastly more probable than in the case of smaller and denser masses. *Rotation*, consequently, would be *the general condition* of nebular masses.

FIGURE 19. MOTION OF THREE NEBULÆ IN SPACE. CASE I, SUB-CASE *a*.

Now, let us consider the two general cases which would arise in the impact of nebula against nebula.

(1.) FIRST CASE.—*The centres of gravity of two nebulæ move toward one point with such velocities as to reach it simultaneously.* We recognize at least two sub-cases.

(*a*) When the centres of gravity move along one straight line. Here in the possible case in which no rotation would ensue, the resultant nebula, in addition to a distorted form, would simply experience an altered motion of translation in space. If three nebulæ, A, B and C, (Figure 19) lie with their centres of gravity in one straight line, each centre of gravity is drawn toward each of the others with a force proportional to the masses and the inverse squares of the distances. At the end of a certain time, B would be drawn by the attraction of A to *b*, and by the attrac-

tion of C, to b'. C would be drawn by the attraction of A to c, and by the attraction of B to c'. A would be drawn by the attraction of B to a, and by the attraction of C to a_2; its resultant place would be, therefore, at a'. The new positions are therefore b', c' and a'. A has made some movement toward B, but C has made more in the same direction. C is therefore approaching A, and will eventually join A, and coalesce with it. The virtual motion of A in the direction of C will therefore cease, and A will move toward B with a velocity increased by the amount by which C's former attraction drew A toward C. That is, the translation of A through space will be augmented by the impact.

(*b*) The second sub-case is when the centres of gravity do not move along one straight line. Here A (Figure 20) is attracted by B and C, and the resultant of the two attractions brings A to a. Similarly, B is attracted by A and C, and takes a course between the two attractions to a. Finally, C is attracted by A and B, and arrives at a at the same instant when, by hypothesis, A and B arrive at the same point. It is evident that there will be no tangential resultant, and no rotation will ensue; but the united mass will undergo a translation in space, in the direction of the resultant of three momenta.

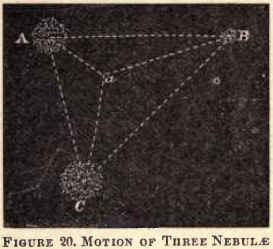

FIGURE 20. MOTION OF THREE NEBULÆ IN SPACE. CASE I, SUB-CASE *b*.

(2.) SECOND CASE.—*The centres of gravity move toward a common point with such velocities as to pass it successively.* The nebula A is attracted by B and by C (Fig. 21. The last figure also illustrates this case, supposing

the three bodies to reach a successively). B is also attracted by C, but owing to relative positions and masses (as we may assume) is less affected by C than A is. A and B both move toward a, but A will reach the point, let us suppose, a little before B. It will be struck by B therefore, tangentially, and both nebulous masses, at least upon their exterior, will acquire a rotation in the same direction. If the deflecting force exerted by C is such that A and B approach each other to a distance but little less than the sum of their radii, they will not coalesce unless their velocities are low, but will each acquire a rotary motion, and each pass on maintaining a separate existence. But if their centres of gravity approach within a distance sufficiently less than the sum of their radii, the two nebulæ will coalesce. Until completely coalesced, they will present the form of a dumb-bell, and afterward, of an irregular spiral, whose irregularity will continually diminish as the coalescence proceeds. In this way, forms like H 1,173 and H 1,622 (Fig. 8) would be evolved.

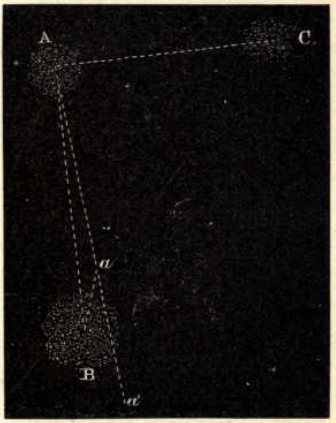

FIG 21. MOTION OF THREE NEBULÆ IN SPACE. CASE II.

It is quite conceivable that nebular rotation might be generated by attraction, in cases where no actual impact

takes place. Suppose an amorphous nebula A (Fig. 22) to be so situated in respect to B, that its longer diameter *a b*, makes an oblique angle with the line A B, joining the centres of gravity of the two nebulæ. One extremity of the mass, as at *b*, will experience a greater relative attraction toward B than the other extremity of the mass will experience; and this inequality will continue as long as the angle B A *b* is not a right angle, and, in the case supposed, as long as B A *b* is less than a right angle. The effect must be to turn the nebula A in such direction that its longer diameter produced will tend to pass through the centre of gravity of B. But in the meantime, B and A may have travelled to widely separated regions of space. The rotation begun in A will therefore continue unhindered. It will continue in any case where the hindering action of B is less than the action which inaugurated the rotation; as for instance when the form of A becomes more symmetrical, though the action of B should be reversed by change of position, without being less.*

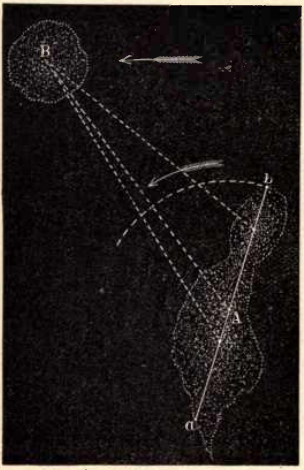

FIG 22. ROTATION RESULTING WITHOUT ACTUAL IMPACT.

* A modern writer of much sagacity has maintained that an amorphous nebula would be made to rotate by the tangential action of currents of nebulous

2. *Causes of Nebular Forms.*—As to the spiral form of nebulæ different suggestions may be made. We may, for instance, conceive it as arising from the action of a resisting medium in space. This would develop a retardation in the peripheral portions, and would explain the tendency of parts to be left behind, as indicated in certain features of spiral nebulæ. Other phenomena would be explained on the supposition of some translation through a resisting medium. The unequal actions resulting from a non-homogeneous constitution of the nebula would favor the production of a spiral form.

Professor Daniel Kirkwood has offered the following suggestion on this subject: "The tendency in a rotating nebula, to unequal angular velocities, resulting from the increased rapidity of condensation from the equator toward the centre, may perhaps also account for the phenomena of spiral nebulæ. If, in a contracting mass of vapor, a free motion of the particles among themselves be established before the centrifugal force becomes equal to the centripetal, a spiral convergence like that of 51 in Messier's Catalogue would naturally ensue."* As the motion among the particles can never be perfectly "free," it is questionable whether the result would not be a stratified nebula, rather than a spiral one. The only probable cause of a descent of particles toward the centre would be their superior inherent density. These, carrying with them the higher linear velocity of the exterior, would tend to run ahead of the particles whose original position was

matter descending from higher to lower levels simply by the action of the central gravity of the mass (Jacob Ennis: *The Origin of the Stars*, 221 seq.). It is, however, a fundamental principle in physics that no rotation could be *generated* in such a mass by the action of its own parts. As well attempt to change the course of a steamer by pulling at the deck-railing. The same author suggests, however, that the attraction of neighboring nebulæ would contribute to the formation of surface currents; and he even suggests the origination of rotary movements by nebular impact.

* D. Kirkwood, *Amer. Jour. Sci.*, II, xxxix, 68, Jan. 1865.

less exterior. Now friction would tend to equalize these motions, but as we may admit that this result would not be accomplished instantly at each stage of their progress, we must conceive a spiral motion of such particles. But there seems to be no probability that the relative number of such particles would be so great as to impart a conspicuous spiral structure to the whole central mass. And if it should, to what could it amount? The motion is from all sides spirally toward the centre; the possible amount of it is therefore limited. The permanent condition of the interior would be either rotation in annuli or rotation with the same angular velocity as the exterior. Evidently, the progressive acceleration of motion in these nebulæ must be from the centre, not toward it — unless the form results from retardation peripherally, as I have suggested.

As to the general internal mass, aside from the descent of particles, as supposed, it rotates with the same angular velocity as the exterior, and in the progress of contraction it undergoes acceleration in the same proportion as the exterior. I think the case may be pushed further. The process of contraction would shorten the radius of revolution of exterior particles a greater amount than the radius of interior particles; and hence the external parts would be more accelerated than the internal; and the internal would rotate with less, instead of greater relative angular velocity.* It is true that a given amount of radius-shortening in the exterior parts would cause less acceleration of angular velocity than the same amount of shortening in the internal parts, since the angular velocity varies inversely as the square of the radius; but in a regular process of shrinkage the radius of revolution of the external particles would be shortened by an amount equal to the sum of the shortenings of the radii of all the particles within it; and this would give the external

* See, further, Part II, ch. I, §2, 2, (2).

particles a much greater acceleration than the internal. Though this is not the nature of Professor Kirkwood's reasoning, we may inquire whether excess of angular velocity in the external parts would not develop a spiral structure. Of course, that would be the tendency, and the motion would not reach a limit, as in the case of internal particles moving spirally toward the centre. The spiral structure, however, would be reversed. But all this peripheral excess of motion would be opposed by mutual friction of parts and by the resisting medium. Nor is it conceivable that the slight residual excess of peripheral motion should develop so strong a tendency to diverge tangentially from the general centre of gravity as is manifest in actual spiral nebulæ. The spiral structure would be close and entirely inconspicuous.

Professor G. A. Hinrichs thinks the spiral form must result, in a large nebula of greatly excessive internal density, from the excessive rotary velocity of the interior portions.* This conception is perhaps not distinct from the last; and the same comments may be made upon it. Furthermore, it implies — what may not generally be true — that the central density was acquired after rotation began; and it must be confessed that rotation is likely to be an early incident of nebular life, and much aggregation of matter is likely to follow. But it may be further said that this central acceleration, should it become a fact, would seem to be a process most likely to arise in an advanced stage of the nebula, when the symmetry of outline would not, by the mere reaction of internal rotation, develop those patchy forms which characterize many of the spiral nebulæ. The spiral form is primitive. It is not a form of equilibrium; it tends to settle into the oblate spheroid; and this is the form to be expected after nebular life has advanced far enough to develop, if it were

* G. A. Hinrichs, *Amer. Jour. Science*, II, xxxix, 141–3.

physically possible, any excessive internal rotation. Finally, any spiral arrangement resulting from excess of internal rotation would be closely coiled, approximating a spheroid, and not by any means the enormous open coils of the actual nebulæ of this class.

Mr. Herbert Spencer has conceived that a multitude of flocculent nebular masses descending from the outer portions of an extensive nebula, would be arranged in a spiral manner;* and an anonymous writer has expressed the opinion that the simple process of contraction in a diffused nebulous mass, or spiral descent of its constituent parts, would develop a spiral form.†

A nebula shaped like a sickle presents the appearance of a nebulous body moving in an orbit through a resisting medium. The resisting medium is probably a fact. The orbital motion would be attributable to two forces—one an impulse exerted tangentially, and the other a constant force exerted centrally. The tangential force it is not difficult to conceive as existing. A central force, indeed, is exerted by every cosmical mass of matter; but a central force ruling the orbital movement of an external body must contain a large mass relatively to the moving body. The central body should, therefore, be as visible as the body moving around it.‡ Now when we contemplate the sickle-shaped nebula H. 3,239 (Figure 7), we detect evidences of the orbital motion of a body, but do not discover the body which could serve as its centre of motion. We might conjecture that such body has not yet become luminous; but even then, the orbit of the revolving body is so small relatively to its volume, that we can hardly suppose a body of sufficient mass could be contained

*Spencer, *Westminster Review*, lxx, 114, July, 1858.

†*North American Review*, xcix, 26, July, 1864.

‡In any case, it will be remembered, whatever the relative sizes of the two bodies, each really revolves around the common centre of gravity between them.

within it. The conception of an orbital motion as the cause of the sickle form presents difficulties which we must try to escape by some different supposition.

Let us assume a considerable mass moving in the direction from B to C, Figure 23. A nebulous mass located at A, would be drawn at first in the direction A B. If it moved in a resisting medium it would become somewhat elongated in that direction — the lightest particles being kept behind. When the attracting body had reached a', the nebula would be drawn toward that point — its direction being slightly changed. So, as the attracting body reached the points a_2, a_3, a_4, a_5, a_6, a_7 and C, the nebula would be drawn successively

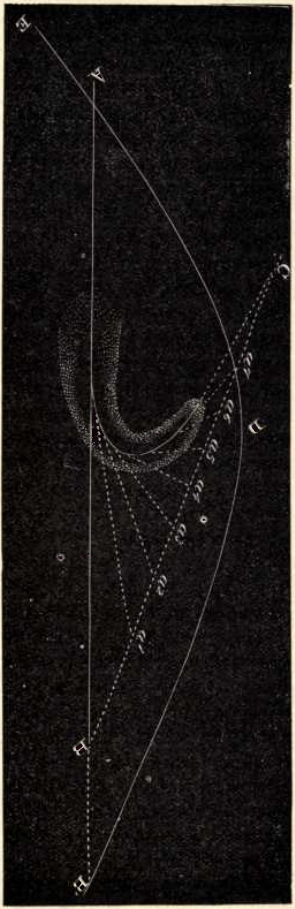

FIG. 23. POSSIBLE ORIGIN OF THE FALCATE FORM OF NEBULA.

toward those points. That is, it would move in a curve with a radius continually diminishing, as long as the attracting body should continue to approach; but with a radius gradually increasing again, after the attracting body should begin to recede. In other words, the path of the nebula would be a curve with two branches somewhat symmetrical with respect to each other.

It ought perhaps to be said that the attracting body feeling the reciprocal influence of the nebula, would not move along the straight line B C, but along the hyperbola B′ D E.

The gyratory motion of a nebula which is not homogeneous would result, in a resisting medium, as I have already indicated, in a spiral form. But, if the nebula should slowly assume a homogeneous character, having similar density throughout each concentric zone, the spiral would be gradually succeeded by a rotating spheroid. A nebulous mass homogeneous from the beginning, and symmetrical in form, would probably never assume the form of a spiral. One appointed form then, of all rotating nebulæ, is that of a spheroid.

3. *Influence of Resisting Medium.*—One suggestion which may be of importance in a subsequent discussion, remains to be made. If a resisting medium act on the motions of nebulous masses in space, it would not only induce a spiral form in a non-homogeneous rotating nebula, but in a homogeneous one would slowly establish a relative retrograde movement of the superficial portions. This, by friction with the deeper portions, would tend to retard their rotary motion, and thus, as a final consequence, the total rotary motion would be retarded. The actual velocity of rotation would never be, therefore, in a nebula continuing to condense after rotation had begun, as rapid as would be demanded by the shortened radius of the rotating spheroid. It may be further said that the establishment of a retarding superficial current would not

necessarily be restricted to nebulæ of uniform density. Whenever the nebulous matter should have become somewhat closely and uniformly gathered together within a certain space, the included portions of the resisting medium would partake of the gyratory motion of the nebula, and the superior power of a denser interior to overcome ethereal resistance would have no opportunity to exert itself. Hence a gradually increasing internal density would not affect the formation of retarding superficial currents in a nebula in this sense non-homogeneous.

Whether rotating or stationary, every nebula is continually wasting its heat. The process of refrigeration is probably retarded by the frequent impact of new accessions of matter. Inevitably, however, the nebula must, in the progress of ages, become reduced in temperature.

4. *Nebular Evolution without Rotation.*—In a non-rotating nebula, especially if possessing an irregular and extremely flattened shape, we may contemplate, besides the general centre of gravity, the centres of gravity of its different portions. Under certain conditions in the course of cooling and shrinkage, a nebula may break up into numerous pieces by a process analogous to a coagulation and withdrawal of part from part (Figure 24), as is daily illustrated in the patchy arrangement of the aqueous vapors which float in our atmosphere.* Under other condi-

FIG. 24.
COAGULATING NEBULA, OR "CURDLING FIRE-MIST."

* Of a certain portion of the nebula in Orion, the so-called Huygenian region, Sir John Herschel writes as follows: "I know not how to describe it better than by comparing it to a curdling liquid, or a surface strewed over with flocks of wool, or to the breaking up of a 'mackerel' sky when the clouds of which it consists begin to assume a cirrous appearance. It is not very unlike the mottling of the sun's disk, only (if I may so express myself) the grain is much

tions, as we may reasonably suppose, liquefied molecules may gather about numerous partial centres of gravity (Figure 25), as was first suggested by Sir William Herschel. In either case, as the cooling should proceed, a cluster of luminous bodies would come into existence, which would present the appearance of a resolvable nebula. This is, perhaps, a mode of evolution of non-rotating nebulæ.

FIG. 25.—FORMATION OF LOCAL NUCLEI IN A NEBULA.

§3. NEBULAR ANNULATION.

1. *The Law of Equal Areas.*—It is probable that most of the nebulæ have rotary motions. It would seem that mutual attractions, if not actual collisions, must, in the great majority of cases, generate rotations in one or another of the methods already indicated. In fact, when we contemplate the delicacy of the adjustment of the forces acting on a tenuous body poised in distant space, and surrounded by millions of other bodies, all changing perpetually their relative distances and positions, it becomes almost incredible that a resultant should *not* arise, in the course of millions of years, which should act, however faintly, as a tangential force. Once stirred from a rigid attitude, a motion is initiated which must change fundamentally the course of nebular development. Let us consider the course of development which the laws of physics necessitate, when a rotation has been inau-

coarser and the intervals darker; and the flocculi, instead of being generally round, are drawn into little wisps. They present, however, no appearance of being composed of small stars, and their aspect is altogether different from *resolvable nebulæ*." (*Memoirs of the Astronomical Society of London*, vol. ii.)

gurated in a mass of highly heated vapor suspended in space.

No proof is required that such a heated body would radiate its heat into surrounding colder space. No proof is required that it would coincidently contract. To suppose otherwise would be to assume an order of nature different from that which all induction has established; and this would bring to a summary end all reasoning on physical subjects. But a shrinkage in the volume of a rotating nebula would necessitate an acceleration of its rotation. By a mathematical principle of physics, known as "the law of equal areas in equal times," the sum of the products of the particles of a rotating vapor into the areas described by their *radii vectores* projected on the plane of the equator, is always, in the same body, a constant quantity. In other words, each radius vector describes the same area, whether its length be increased or diminished; and hence, if its length is diminished its angular velocity must be increased to enable it to sweep over the same area in the same time. This principle, thus enunciated, may not be quite clear to some of my readers, and I will endeavor at least to render intelligible the meaning of the proposition, though its proof could not be presented without resort to mathematical operations.

Let us suppose that in Figure 26 the circle A B C represents a section through a rotating sphere of heated vapor, in the plane of its equator. The circumference A B C is, therefore, the equator, and it may be conceived as represented by a series of particles linearly arranged. Let one of these particles be at *a*, then *a* O, drawn from it to the centre of the circle, is its radius vector. If, in the progress of rotation, the particle *a* is transported to *b*, its radius vector will sweep over the space between O *a* and O *b*. But suppose that in the course of time, cooling has contracted the sphere to such extent that when the

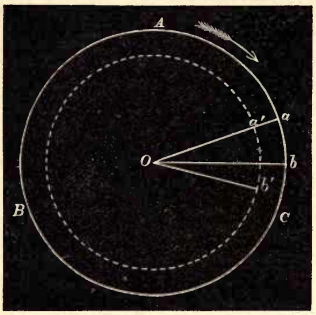

FIG. 26. THE "LAW OF EQUAL AREAS,"

same molecule arrives in the same angular position as before, it is not at a, but at a'. Its radius vector is now $O\,a'$, a certain amount shorter than before, and if it sweeps forward with the same velocity as before, it will not sweep over the same area in the same time as before. It must, therefore, move more rapidly, so that in the same time which formerly carried it from a to b, it will now be carried from a' to b', making the area $a'\,O\,b'$ equal to the area $a\,O\,b$. If these statements are true of one particle in the circumference of A B C, they must be true of all the particles in that circumference. But immediately within this circumference we may conceive another, the particles of which are moved in every respect exactly like those in the circumference A B C, except that their absolute velocity is less all the time. As the sphere contracts, these particles also will move with accelerated velocity. But within the last named circumference we may conceive others, until the whole area inclosed within A B C is seen made up of a series of concentric circles of particles, each particle rotating according to the same law as the particle at a. Next, we may easily conceive that another sheet of particles is immediately contiguous to this one on each side. The motions of its particles, it will readily be understood, are controlled by the same law of equal areas. It follows that the rotation of the whole sphere, which is

made up of parallel sheets of particles, must be accelerated in the same manner as the particle at a, during a process of cooling and contraction of the mass.*

The same conclusion may be reached from the principle that the angular velocities of two rotating spheroids having the same mass and the same angular momentum, but of different equatorial diameters, are to each other inversely as the squares of their radii of gyration.† The radius of gyration is the distance from the axis of rotation to the centre of gyration, or point within the mass at which we can conceive an opposing force applied which would completely arrest the rotation without jarring or wrenching the axis.

Not only is the *angular* velocity increased, but the actual velocity of the periphery also; and it is chiefly the increase of the actual velocity which increases the centrifugal force of a particle. Some critics fall under the misapprehension of considering only angular velocity.‡ That contraction increases the actual as well as the angular velocity is obvious from the simple consideration that the centrifugal force of a particle at the equator is measured by the square of the actual velocity divided by the radius

*In this explanation, the particles, for the sake of simplicity, are assumed to be all of the same mass. Thus under the principles enunciated, they become a common factor which may be cancelled.

† The angular momentum of a spheroid whose mass is M, axis of gyration, k, and angular velocity, θ, is

$$Mk^2\theta.$$

Supposing the same mass to have contracted till its axis of gyration is k' and the angular velocity θ', its angular momentum will be expressed by

$$Mk'^2\theta'.$$

But as the angular momentum remains constant, we have

$$Mk^2\theta = Mk'^2\theta',$$

whence

$$\theta : \theta' :: k'^2 : k^2.$$

And for a particle in the periphery, k and k' equal the radii vectores r and r' in the two positions, and we get

$$\theta : \theta' :: r'^2 : r^2,$$

That is, the angular velocity increases as the square of the radius vector of the particle diminishes.

‡ Rev. W. B. Slaughter: *The Modern Genesis*, pp. 85–87.

of the equator. Since, therefore, the radius is continually diminishing, the actual velocity is continually increasing.*

2. *Abandonment of a Ring.*—Let it be granted then, that the process of necessary cooling and contraction would be accompanied by an accelerated rotation. This would be accompanied, in turn, by an increased oblateness at the extremities of the axis. As soon as rotation begins, the momentum of the particles around the equator is greater than that of particles on either side, and it continually decreases to the poles, where it is nothing. The momentum of a particle measures its tendency to fly off in a tangent or straight line in the direction in which the particle is moving at any instant. This is a tendency which, in part, draws it away from the axis around which it moves. As the velocity of rotation increases, each particle must therefore experience a stronger tendency away from the axis of rotation. As this centrifugal tendency is greatest at the equator, the equatorial parts will protrude, and, if there is any mutual attraction among the particles, those on each side of the equator, aided by centrifugal tendency, will flow away from the poles, and thus diminish the polar diameter, while the equatorial is increased. In other words, the sphere will become an oblate spheroid, with oblateness increasing in proportion as the velocity of rotation is increased.

What must this process end in? Evidently, the oblateness will finally reach such an extent that the equa-

* Letting v and v' represent the actual velocities of a particle, m, in the two situations, before and after a certain amount of contraction, and r and r' the two corresponding values of the radius vector, the centrifugal force in the two situations will be $\frac{m\,v^2}{r}$ and $\frac{m\,v'^2}{r'}$. But as the centrifugal force varies directly as the centripetal force, that is, inversely as the square of the radius vector, we have

$$\frac{m\,v^2}{r} : \frac{m\,v'^2}{r'} :: r'^2 : r^2.$$

From which $\quad v^2 : v'^2 :: r' : r.$

But $\quad r > r',\ \therefore v'^2 > v^2$ or $v' > v.$

torial particles will have a centrifugal tendency equal to the centripetal. Then, if any further contraction of the spheroid takes place, the equatorial particles will not follow, but will be left suspended in equilibrium between the two tendencies. An entire equatorial ringlet of particles will attain this equipoised condition, and the remainder of the mass will proceed to shrink away from it. (See Figure 27.)

3. *Width of the Ring.*—Now, if we could neglect the mutual attractions of contiguous particles, it is apparent that this ringlet would be extremely narrow and thin. As soon as detached another slender ringlet would separate itself, and then immediately another, and so on. The series of slender concentric ringlets thus detached would constitute virtually a broad, flat and thin ring, having a slower rate of rotation on its outer margin than on its inner. If these closely contiguous ringlets should actually coalesce, the friction of outer and inner ones would accelerate the outer and retard the inner until the angular velocity of all would approach uniformity. But, disregarding mutual attraction of the parts, we see no cause to limit the process by which slender ringlets would be formed, until the whole mass of the spheroid should be reduced to a rotating disc essentially continuous from centre to circumference. But here two suggestions must be made. The discoid arrangement would be but a momentary phase in each concentric ringlet, because (1), when we carry the conception to the extent indicated, we perceive that disc-like continuity from ringlet to ringlet is incompatible with the physical tendency to ever increasing velocity toward the centre in proportion as the contraction is actually experienced toward the centre. (2) Such a disc could not subsist in the case of a fluid substance. It would gather itself into a single ring. The transverse section of the ring would be ovate, with the smaller end

turned toward the axis of rotation. Whatever we might conceive to result from unequal velocities in a flat ring of relatively limited extent, it is evident that no permanent disc-like continuity of successively equilibrated matter could ever take place to any relatively considerable extent. Instead of a broad and continuous disc, we must have a series of concentric rings rotating with different velocities. Nor is it supposable that closely approximated ringlets, circumstanced as suggested, would perpetuate their common existence until some epoch when a common crisis should simultaneously change the condition of newer and older alike.*

Undoubtedly, mutual attractions of contiguous particles and masses always existed, and hence we have no occasion to speculate on the consequences of an absence of such attractions. If then, we turn back in thought to the epoch when the first equatorial ringlet of particles should have been left detached from the shrinking remainder, we perceive that the next inner circle of particles must be actuated by a centripetal force barely sufficient to overcome the centrifugal tendency experienced in that circle. But exterior to these particles is the ringlet of particles just disengaged, and its attraction would completely neutralize the slight excess of centripetal force experienced by the second ringlet, and this ringlet would therefore be brought into a state of equilibrium, and would also be left. Now the third ringlet would experience a stronger predominance of centripetal force, but this would be opposed by an increased attraction exerted by the two ringlets exterior to it. We may therefore conceive that a third, and other ringlets would almost simultaneously become detached. How broad and massive

* It has been suggested that such a history is supposable. See D. Kirkwood, *Amer. Jour. Sci.* II, xxxviii, 5; D. Trowbridge, *id.* note; S. Newcomb: *Popular Astronomy*, 497-8; Du Prel: *Die Planetenbewohner*, 6.

the aggregate ring would be, would be determined by the position of the nascent ringlet at which the centripetal force should exceed the centrifugal force (at that distance from the axis) added to the attraction of the annular mass exterior to it. Now every successive addition which may have been drawn to the annular mass increases its distance from the next ringlet of particles, and upon this its influence, though increasing with the growth of the ring, diminishes as the square of the distance increases. Its influence, that is its contribution to the centrifugal tendency of the next ringlet, diminishes, therefore, more rapidly than the centripetal tendency is diminished by diminution of the residual mass, for that is as the first power of the mass; and it increases as the square of the radius of the spheroid is diminished by contraction. The influence of the ring diminishes more rapidly than the joint effect of diminished residual mass and increased rate of rotation. This circle of equilibrium would determine, therefore, the line of separation between a segregating annular mass and the residuum of the spheroid. In other words, *an annular mass of relatively considerable amount would separate, and a secular interval would intervene before the separation of another annular mass.** The condition represented by Figure 27 may therefore be contemplated as one of the primitive phases of a rotating nebula. It is observed to actually exist in certain stellar nebulæ, as H 450.

FIG. 27. NEBULA IN PROCESS OF ANNULATION.

The foregoing exposition assumes that the actions concerned would reach their resultant somewhat simultaneously, and the ring would be formed without any considerably

*Compare D. Trowbridge, *Amer. Jour. Sci.*, II., xxxviii, 35.

prolonged period of growth. The influence of progressive contraction of the nebula is therefore neglected. But contraction would proceed during whatever period might be occupied in the formation of the ring. We may consider, therefore, what would result on the assumption that no ringlet, after the first, would leave the nebula until entirely equilibrated between centripetal and centrifugal tendencies. This assumption depends on progressive contraction and acceleration for the successive disengagement of ringlets. It will give a clearer conception of the

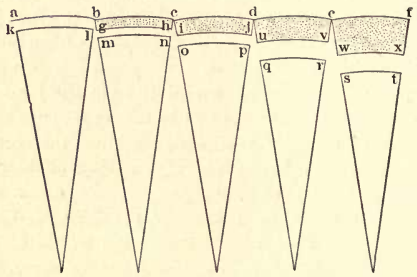

FIG. 28. ILLUSTRATING THE DETERMINATION OF THE WIDTH OF A NEBULOUS RING.

conditions limiting and determining the width of the ring produced. Let *a b* (Figure 28) represent a segment of a slender ringlet just abandoned, having the slight interval *a k*, separating it from the new periphery of the nebula. Soon the peripheral ringlet *k l* will attain a state of equilibrium. This experiencing a positive attraction from the ringlet *a b*, and no tendency to fall toward the centre of the nebular mass, must move toward *a b*. The external ringlet becomes thus augmented to the breadth shown

in $b\,c$, and the interval between it and the nebula is enlarged to $g\,m$. Next, another ringlet $m\,n$ attains a state of equilibrium, and will similarly be drawn to $b\,c$, augmenting the external ring to the breadth $c\,i$ shown in $c\,d$. In due time the ringlet $o\,p$ is abandoned and drawn to $c\,d$, augmenting it to the width $d\,u$ as shown at $d\,e$. I do not conceive the actual formation of distinct ringlets of any definable magnitude, with an actually periodic passage from the periphery of the nebula to the growing ring. The abandonment of ringlets is momentary and continuous, and the passage of the nebulous matter outward is in the nature of a continuous flow which fills the intervening space with an extremely attenuated nebulous medium.

At length the breadth of the growing ring becomes such as is represented at $e\,f$, and the interval between it and the nebula has widened to $w\,s$. Meantime the attraction of the ring exerted upon the periphery of the nebula has been continually diminishing as the square of the distance increased. It has become diminished to such an extent as to be comparatively feeble. A differential ring $s\,t$, feels now a different preponderance of forces. The attraction of the ring does not cease to be felt to some extent; and the attraction of the nebula does not cease to be neutralized by the centrifugal tendency. But there have all along been two actions opposing the passage of matter to the ring which have not yet been mentioned. One of these is the friction of the ether and meteoroidal matter, which continually retards the velocity of rotation, and all the more where a mass as thin as the withdrawing ringlet is concerned. This diminishes the centrifugal tendency, and opposes the passage outwards. Besides this, the mutual attraction of contiguous parts of the ringlet at all times opposes that distension implied in the transformation to a ringlet of greater circumference. The joint action of these comparatively minute forces determines

a critical moment. The diminished attraction of the ring now ceases to overcome them. A ringlet is formed at *st* which remains unmoved from its place. It constitutes the starting point of another ring, which, in turn, goes through a similar history.*

Under certain conditions the growth of the ring would not attain its limit until the nebula had been entirely exhausted. The nebula would be thus transformed into an annulus. If the resistances of friction and the mutual attraction of parts of the ringlets should in any case be inconsiderable, the attraction of the ring would always preponderate over the forces opposed to the translation of matter to it, and the growth of the ring would be indefinite.†

It does not seem unreasonable to suppose that under certain conditions, as for instance, an extraordinarily rarefied condition of the central part, the centrifugal tendency of the peripheral parts and the attraction of the nascent ring for successively more interior nascent rings should result in expanding the entire mass of the nebula directly into an annulus. This tendency once inaugurated, by the

* Let G′ = attraction of the ring upon the nearest point of the nebula, *i.e.* sum of the components (of all the attractions of the ring) which act along the shortest line from the point to the ring.

G = atttraction of nebula upon the same point.

F = centrifugal tendency of the same.

e = sum of frictional resistances to its motion.

m = sum of mutual attractions opposing separation of particles.

Then, as long as we have

$$G' + F > G + e + m$$

the ring will continue to increase in breadth. When

$$G' + F = G + e + m$$

the ring will cease to receive accessions of new ringlets. Thenceforward we shall always have

$$G' + F < G + e + m.$$

† Since, in this case, $e + m = 0$, and by hypothesis G = F at all times when annulation is possible, the expression $G' + F > G + e + m$ reduces to $G' > 0$, an inequation which expresses the condition of ring-growth, and will continue true until $e + m$ becomes such that $G' = e + m$. But if the last relation is never reached, the growth of the ring will be unlimited as long as the nebula is unexhausted.

vacation of the central region, the effect of further contraction would be, in a highly tenuous condition of the nebula, to enlarge the diameter of the vacant interior, as well as to diminish the outside diameter of the ring.

A tendency of this kind to the simple annulus is by no means imaginary. The central attraction of parts near the centre would, on physical principles, be slight, since nearly as much matter would lie upon the side toward the periphery, *b*, Figure 29, as on the side toward the centre, *c*. At the centre the balance of tendencies would be complete. The periphery and the centre would therefore be, by hypothesis, both in equilibrium. The periphery would experience no tendency to move toward the centre. The central portions would experience little or no tendency to remain there. Meantime both parts attract each other. The periphery, with progressive shrinkage, might move toward the centre until accelerated velocity should nullify the attraction of the central portion. The latter portion would move, by its own gravity, toward the periphery, until a state of condensation should be reached, such as to correspond with the existing temperature. Thus, I imagine, a simple annular nebula might originate, such as we are acquainted with in the Lyre (Figure 11), in H 1,909 and H 2,621.

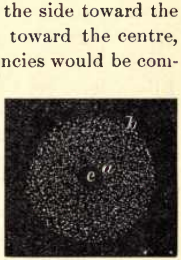

FIG. 29. NEBULA, BECOMING ANNULAR.

Thus, nebular aggregation and secular refrigeration may reasonably be regarded as the general causes of the varied forms, conditions and evolutions of nebulæ. Let us now attempt to trace the development some steps farther.

*Schellen: *Spectral Analysis*, 555 and 542, Figures 192 and 193.

4. *Non-annulating Nebulæ and Stratified Rings.*—The progressive changes of nebulæ seem to be toward the stellar condition. Not improbably, many nebulæ, especially small ones, shrink into single stars, as Sir William Herschel supposed. Some of the planetary nebulæ may possibly contract indefinitely without breaking into separate nebulous fragments. In either event, they appear to undergo a sort of annulation.

It seems more probable, however, that most nebulæ break up normally into a large number of partial masses. I have indicated a process of curdling as a possible step in the stellation of a non-rotating nebula. Each separate mass may be regarded as embracing in some instances, material for a sun and planetary system. This idea, however, supposes that a rotation comes into existence in each mass. How this could be generated while the physical conditions are such as to favor the segregation of the masses, and thus prevent that precipitation of mass upon mass which is the most obvious cause of nebular rotations, I am not able to understand.* I must leave the discrete, non-rotating nebula, if such really exists, for the further developments of science.

As to rotating nebulæ, I have shown that they tend to annulation. A ring of nebulous matter, if little disturbed by external perturbations, may rotate indefinitely around its centre of gravity. The process of shrinkage in a persistent rotating ring of nebulous or pulverulent matter would, in some cases, result in a stratification, or sepa-

* I formerly regarded nebular collisions as many times the most probable cause of rotations; but later reflection leads me more and more to the conviction that simple mutual attractions upon amorphous forms suspended in space, are competent to generate universal rotations. It becomes more and more apparent that rotation is *inevitable*, and that it must exist even in the planetary and curdling nebulæ. The latter are resolvable nebulæ which nevertheless give a spectrum of bright lines, and hence, must consist of nebulous matter in a discrete condition. Such is the nebula or "cluster" in Hercules. Even the separate masses of a curdling nebula must sooner or later rotate.

ration of the ring into two or many concentric rings (Figure 30). The stratified condition might also arise, as Kant first suggested, from the different velocities of the outer and inner portions of a broad ring progressively disengaged. It is also quite conceivable that every annular mass, separated after a secular interval, should consist originally of differential annuli dropped off in small consecutive elements of time. These, if ever existing, which is not probable, must naturally experience a strong tendency to coalescence in groups, at the same time that their different angular velocities might resist the coalescence together of rings differing much in diameter. Be the cause of stratification what it may, it seems to be at least an occasional incident of nebular life. A persistent example is actually noted in the rings of Saturn.

FIG 30.—STRATIFICATION OF A NEBULOUS RING.

§ 4. SPHERATION OF RINGS.

1. *Disruption of a Ring.*—Sooner or later, external perturbations or actual collisions must generally result in the breaking up of a nebulous ring. In some instances perturbation would develop undulations which, continually exaggerated, would finally produce rupture, or destroy the equal distribution of matter around the ring. An increase of mass on one side, however caused, would draw still other matter toward it. The ring on the opposite side would become slender (Figure 31), and would

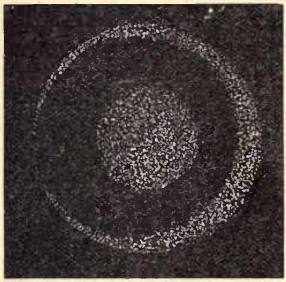

FIG. 31.—NEBULOUS RING UNDERGOING RUPTURE.

finally part. The annular mass would now rapidly gather itself into a spheroid (Figure 32), which would continue revolving in a path determined by the position of the transformed ring. It seems possible that such process of aggregation might take place at two or more points in a ring, and this is the view which was entertained by Laplace. In such case, there would result a corresponding number of spheroids; but these would sooner or later coalesce in one. No two bodies could continue permanently to revolve in one orbit.

FIG. 32.—SPHERATION OF A NEBULOUS RING.

C. S. Cornelius, in an essay of much originality, has advanced the opinion that the separated ring would attract to itself some neighboring portions of the abandoned nebulous spheroid. These portions, he assumes, would join the ring with a smaller rotational momentum, and the union of parts thus differing in energy of rotation would strain the ring to such an extent as to rupture its continuity. Each of the resulting partial spheroids would rotate in the original direction. But the larger of these would eventually unite all the others in itself.*

* Vereinigte nun der sich ablösende Ring durch Anziehung die zunächst angrenzenden Theile der Dunstkugel mit seiner Masse, so musste derselbe ver-

The breaking up of a set of concentric rings would result in a corresponding number of rotating bodies, which would be likely, in some cases, to remain isolated.

By some such means repeated a number of times, the entire nebula would be reduced to an assemblage of partial nebulous masses, all revolving in orbits about the original centre of gravity.*

2. *Rotation of Resulting Mass.*—It may be set down as a necessary result that the mass derived from a ring would possess a rotary motion about some axis. By an infinity of chances to one, the resultant of all the external forces acting upon it would not pass through the centre of gravity. But the mode of connection between the derived spheroid and the parent mass would be the principal determinative circumstance. The lines of interaction between the two would be located nearly in the plane of the equator of the original mass; and hence the probable rotation would be in that plane. We have then to consider whether the rotation would be direct—that is, in the same direction as that of the primitive nebula—or retrograde.

The ring before spheration possessed a certain amount of breadth. Laplace conceived that the external and internal zones of the ring would rotate with the same angular velocity, which would be the case with a solid ring; but the principle of equal areas requires the inner zones to rotate more rapidly than the outer. The determination of the relative velocities of the outer and inner zones is the

möge der abweichenden Rotationsgeschwindigkeit und Schwungkraft der angezogenen Theiln, so wie auch in Folge von Molecularkräften seinen Zusammenhang verlieren und in mehrere Stücke zerfallen. * * * Das grösste Bruchstück des Ringes mochte nun insgemein die kleineren Stücke herbeiziehen und sie mit seiner Masse vereinigen. (*Entstehung der Welt*, p. 18. Leipzig, 1870).

* The stability of a ring, while possible, is something with a high order of chances against it. See Maxwell: *On the Stability of the Motion of Saturn's rings*, and B. Peirce, *Gould's Astronomical Journal*, ii, 17, 18.

solution of the problem of the direction of the rotation of the derived spheroid.

I have maintained, when speaking of the periodicity of ring-formation, that friction, cohesion, and mutual attractions of the parts of a separating ring must exist to such an extent as to render annulation periodic. If I am correct in this opinion, it is manifest that friction, cohesion, and mutual attractions of the outer and inner zones of the ring would tend to equalize the angular velocities of the outer and inner portions. Let us assume, in the first place, that the equalization of external and internal motions becomes nearly complete. The remotest side of the derived spheroid would then accomplish a revolution about the parent mass in the same time as the nearer side. The nearer side would remain turned toward the parent mass during the entire revolution. This is equivalent to saying the derived mass would complete one rotation on its axis while performing one revolution in its orbit. The motion would be *direct*. The relations assumed are the condition of direct rotary motion.

If we had no concomitant interference to consider, it is manifest that the direct rotation thus inaugurated would be accelerated by subsequent cooling and contraction, and the primitive synchronism of axial and orbital motions would immediately cease to exist. As the final amount of acceleration in a rotating spheroid contracting in consequence of loss of heat, depends on the amount of contraction, and this depends on the amount of matter, it is obvious that the final velocity of rotation must be proportional to the mass. Large masses in advanced stages of their existence should have a more rapid rotation than small masses in corresponding stages. All masses must experience acceleration proportioned to the total amount of contraction undergone.

The derived mass might be of such magnitude as to

retain its nebulous state long enough, and acquire rotary acceleration enough, to enter, on its own part, upon a process of annulation. This system of disintegration, so far as concerns the forces which inaugurated it, must continue until the augmentation of paracentric force can no more become sufficient to equalize the sum of the force of gravitation and the resistance of rigidity. The whole history of acceleration and disintegration is independent of the direction of the motion.

The subsequent evolutions thus enunciated would begin immediately on the spheration of a ring, if no external interference were experienced. To this point I shall hereafter return.

Let us next consider what would happen if the relative velocities of the outer and inner zones of the nebulous ring should be determined in full accordance with the principle of equal areas. In this case, the velocity of the inner zone would as many times exceed that of the outer, as the square of its distance from the centre of motion is less than the square of the distance of the outer zone from the centre of motion. So far as this circumstance is concerned, the nearer side of the derived spheroid would tend to perform its circuit about the primitive centre in less time than the remoter side. But, as we assume all parts to be held together, the result would be a *retrograde* rotation of the derived spheroid. The subsequent cooling, contraction and acceleration would proceed exactly as in the case of direct motion.

Now, reflection upon this subject has led me to the conviction that the physical relations accompanying the spheration of a ring are not such as to determine uniformly either direct or retrograde motion. Under certain circumstances the motion would be direct; under other circumstances, it would be retrograde. It seems probable the consistency of a nebulous mass and its rate of condensa-

tion internally would be such generally, that the actual relation of velocities of the outer and inner zones would be somewhere *between* uniformity and that determined by the principle of equal areas.

Since we may fairly assume the influence of friction, cohesion and mutual gravitation of parts to have some real existence in a nebulous ring, there must be constituted, so far, a *tendency* to equal angular velocities in the inner and outer zones, and a corresponding predisposition to direct motion. So far as the law of equal areas is concerned, there must exist a predisposition to retrograde motion. These two predispositions must always exist, and they must always contend against each other. The preponderance of the one will give direct motion; the preponderance of the other will give retrograde motion.

But we understand the principle of equal areas is an absolute physical law whose action, disregarding mass (since in this question we may deal always with equal masses), is always with efficiency inversely proportional to the square of the radius vector. The measure of this efficiency is the difference of the squares of the radii vectores of the outer and inner zones of the ring. Against this contends a set of influences which vary with circumstances. Friction will vary with the pressure upon the contiguous parts, and this will vary with the mass in a section of the ring. Cohesion will vary with the kind and state of the matter. The mutual attraction of parts will vary with the mass in the section and the distances of the centres of the partial masses.

Under what circumstances will these variable influences attain a maximum? In other words, when will direct motion be most likely to ensue? Manifestly, when the nebulous matter is most condensed, and most acted upon by the attraction of the parent mass. That is, when the

progress of annulation has reached somewhat toward the central portion of the nebula. When will the opposing principle of equal areas possess least efficiency? Manifestly, when the rings are narrowest. That is, when the density of the nebula reduces the period during which a forming ring may continue to receive accessions. In other words, in the later stages of annulation. It is, therefore, in the later stages of annulating life that the predisposition to direct motion is greatest, and the predisposition to retrograde motion is least. It is perfectly rational to suppose, finally, that the derived spheroids resulting from later evolutions should possess direct motion.

These conditions are all reversed in the earlier stages of the annulating history of a nebula. In the peripheral portion of the nebula, diminished gravitation operates less efficiently in restraining the accession of matter to the forming ring, and thus allows the ring to attain greater breadth. In the primitive epoch also, the great tenuity of the matter implies diminished friction and cohesion, and correspondingly implies a more rapid contraction, and a greater prolongation of the period of ring-growth. It implies, in other words, a greater breadth of ring, and a greater efficiency of the principle of equal areas; and a correspondingly stronger predisposition toward retrograde motion. It is perfectly rational to suppose, finally, that the derived spheroids resulting from earlier evolutions should possess retrograde motion.

This conception of physical relations renders it probable that the same nebula would evolve earlier secondaries inheriting retrograde axial motions, and later secondaries inheriting direct axial motions. This state of things partially exists in our solar system. But the considerable deviation of the equators of the Neptunian and Uranian systems from coincidence with the plane of the sun's equa-

tor should cause hesitation in accepting the foregoing views as a full explanation of their anomalous motions.*

*The reasoning here employed may be made a little more tangible by the use of algebraic notation.

Let R′ = radius of inner stratum of ring.

R″= radius of outer stratum of ring.

v' = linear velocity of inner stratum of ring.

v''= linear velocity of outer stratum of ring.

Then, supposing the angular velocities of the two strata equal, we have

$$v' : v'' :: R' : R''; \therefore v' = v'' \frac{R'}{R''}.$$

This is the condition of *direct* motion.

But supposing the outer and inner strata to have velocities according to the law of equal areas, we have

$$v' : v'' :: R''^2 : R'^2; \therefore v' = v'' \frac{R''^2}{R'^2}.$$

This is the condition of *retrograde* motion.

When the value of v' is at a certain point between $v'' \frac{R'}{R''}$ and $v'' \frac{R''^2}{R'^2}$, there will be no rotation. Let x represent the excess of that value over $v'' \frac{R'}{R''}$, and y, the excess of $v'' \frac{R''^2}{R'^2}$ over the same value. Then

$$v'' \frac{R'}{R''} + x = v'' \frac{R''^2}{R'^2} - y.$$

This is the condition of *no* rotation.

But any change in values which will make

$$v'' \frac{R'}{R''} + x > v'' \frac{R''^2}{R'^2} - y$$

will result in *direct* motion. This inequation will arise

(a) When R′ increases or R″ diminishes — that is, *when the breadth of the ring diminishes.*

(b) When R′ and R″ diminish equally in arithmetical ratio — that is, when they pertain to *a smaller ring* having the same breadth and rotary velocity.

(c) When v'' diminishes, the other quantities remaining constant, or R′ and R″ also diminishing in equal arithmetical ratio—a condition in the later annulation of a mass having great central condensation.

Also, any change in values which will make

$$v'' \frac{R'}{R''} + x < v'' \frac{R''^2}{R'^2} - y$$

will result in *retrograde* motion. This inequation will arise

(a) When R′ diminishes or R″ increases—that is, *when the breadth of the ring increases.*

(b) When R′ and R″ increase equally in arithmetical ratio—that is, when they pertain to a larger ring having the same breadth and rotary velocity.

(c) When v'' increases, the other quantities remaining constant, or R′ and R″ also increasing in equal arithmetical ratio—a condition in the earlier annulations of a mass having great central condensation.

From all which it appears that while *direct* motions must probably prevail

It ought to be remarked also, that the probability of retrograde motions in the earlier history of annulation would increase with the volume of the nebula. Because, in a larger nebula, the difference between peripheral and central condensation is greater, and here would exist a greater difference in the influences of friction and cohesion in the earlier and later processes of annulation. We should infer, therefore, that in a relatively small nebula all the rotations would be direct. This inference is exemplified in the Saturnian and Jovian systems of satellites; and probably also in the Uranian and Neptunian, where direct motion would be motion in the direction of the rotation of the primaries.

Some investigators of this subject have assumed the position that the primitive rotation of the derived mass must in all cases be retrograde.* They ignore, however, the influence of friction and cohesion. Others have attempted to show that retrograde motions either must or might arise in the earlier annulation-history, while direct motion would ensue in the later history.† The conclusion is the same which I have reached by a method which seems more intelligible and convincing. Professor Hinrichs shows that the rotary motion will be direct, zero or retrograde, according as the primitive density of the nebula in the part where the orbit becomes located, was greater, equal to or less than a certain quantity depending on the position of the orbit in the ring, and on the law of variation of the density. If the variation in density were zero,

in the regions nearer the centre, *retrograde* motions may arise in the regions remoter from the centre.

It may be added that the actual occurrence of direct motions in our system is evidence that the inner and outer strata of the corresponding rings did *not* possess velocities adjusted fully to the law of equal areas.

*D. Kirkwood, *Amer. Jour. Sci.*, II, xxxviii, 2-4; D. Trowbridge, *Amer. Jour. Sci.*, II, xxxix, 25-6.

†G. Hinrichs, *Amer. Jour. Sci.*, II, xxxvii, 51; M. Faye, *Comptes Rendus*, xc, 640.

all the derived spheroids would have direct motion. But if the density diminished from the centre, however slowly, then the earlier formed secondaries would have retrograde motion, and the later direct motion. The conclusion is based solely on relations of density, interannular spaces, and position of resulting orbit in the ring.

Mr. Faye, adopting an analytical expression* for the law of increase of density toward the centre, determines that the linear velocities of the internal parts will go on increasing in diminishing ratio from the circumference to a certain distance from the centre, when the linear rotary velocities will begin to decrease. Thus he concludes that the annulating-life of a nebula would be divided into two periods, during the first of which the rotary motions of the derived masses would be retrograde, while during the other they would be direct. But it does not appear evident that the superior linear velocity of the remoter parts would suffice as a sole cause for effectuating retrograde motions. Such motion must result from a certain *ratio* of outer and inner velocities, and this depends, as I have shown, on the *breadth* of the ring and the influence of friction and cohesion. M. Faye takes no account of the influence of friction and cohesion, while, so far as I understand the subject, the possibility of direct motion at any stage depends on the preponderating influence of friction and cohesion.

It is not necessary to assume that axial rotation would be impressed only by the forces already mentioned. If two or more spheroidal masses should result from the rupture of a nebulous ring, and should afterward coalesce, their impact must generate a rotation, as heretofore explained. But such rotation would as probably be in one

* $D\left(1-\beta\sqrt[n]{\frac{r}{R}}\right)$, where D is the central density of the nebula, R the radius of its equator, r the distance from any point to the center, n an arbitrary positive number, and β a very small fraction.

direction as another, except so far as the synchronous rotation, always necessarily existing in the primitive stage, should predispose to a rotation in the established direction.* In spite of this there ought to be some cases in which the motion would be retrograde, or the axis of rotation far from perpendicular to the plane of the orbit. In addition to this, it remains to be said that every external attraction experienced by the forming spheroid, until its form should have attained mathematical symmetry, would tend to inaugurate rotation, or change any existing rotation, under any of the conditions pointed out in discussing the origin of nebular rotation in general.

3. *The Influence of Cosmic Tides upon the Rotation of the Derived Spheroid.*†—We come now to consider the interferences before alluded to. Supposing the derived spheroid to be affected by a motion of rotation, the acceleration of its rotation would not immediately proceed step by step with the progress of cooling and contraction. Such acceleration would be opposed by the prolate deformation which would arise through the differential momenta of its own parts, and the differential attractions of the central residual mass exerted on a mass of such mobility of parts as the incandescent vapor which we are considering. By hypothesis, the centre of gravity of this new sphere is at such distance from the parent mass as to be poised between centripetal and centrifugal tendencies. The remoter point *a*, Fig. 33, must therefore experience an excess of *centrifugal* tendency in consequence of its greater velocity, and would only be retained by the attraction of the derived mass. It would indeed tend to retire from *c* until the centrifugal force due to rotation about *o*

* In this connection the various inclinations of the planetary axes in the solar system are somewhat suggestive. The inclination of Venus amounts to 50°, while that of Uranus and Neptune is generally considered to be over 90°.

† The influence of tides in cosmical history will be more fully considered hereafter in connection with planetary vicissitudes.

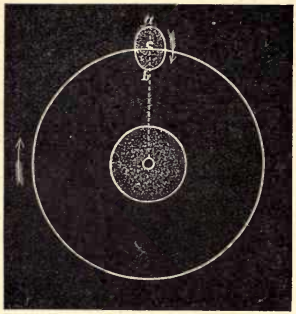

FIG. 33.—PROLATENESS AND ROTATION OF THE DERIVED SPHERIOD.

should be balanced by the central attraction directed toward *c*. On the contrary, the parts at *b*, having now the same angular velocity as the other parts, but a slower actual velocity, the *centripetal* tendency would be in excess, and they would extend toward *o*, until this excess should be counterbalanced by gravitation toward *c*.* Concurrent with these actions would be the difference of attractions exerted by the parent mass upon *a* and *b*, raising veritable tides in those opposite regions. Thus, a prolate spheroid would come into existence, whose stability would persist for a certain period. But the contraction of the mass and the increasing effort to accelerate the gyration might ultimately destroy the synchronism between axial and orbital motions.

There is this further to be said of a prolate aëriform mass situated as described, and constrained toward accelerated rotation. It must not be viewed as a rigid body. All its parts possess excessive mobility. The superficial particles at *a*, under an impulse to accelerated motion, would *flow*, on the assumption of an effort toward direct motion, in the direction of the arrow, toward *b*, if the general mass were restrained from a consentaneous movement. Parts at *b* would experience a similar tendency

* While this reasoning discloses a true cause of prolateness or tidal elevation, it is not conceived to be the most efficient cause of tides, especially upon the larger of two spheroids tidally connected together and differing greatly in mass.

to flow in the same direction. Thus superficial currents would be established; and these would deepen and involve more and more of the whole mass. In proportion as the *flow* of these currents should be established and deepened, the attainment of accelerated rotation of the general mass would be accomplished; and ultimately the whole mass would possess a rotation more rapid than the orbital rotation. Thus, perhaps, might an axial rotation be acquired nearly corresponding with the acceleration due to the contraction of the mass after the earliest epoch of spheration. But the prolateness would never disappear, and would only diminish in proportion as the molecular mobility should diminish by condensation, by cooling or some other cause. Different sides of the derived spheroid would consequently be raised successively into a tidal protuberance. The consequence of this would be a perpetual relative displacement of the different parts in respect to each other,* which might be compared with the effect of rolling an india rubber ball between the hand and a surface on which the ball is pressed.

The prolate condition of the new spheroid may be contemplated without regard to the relative motions of its constituent parts. It hangs balanced by a support fixed at the centre of the forces acting upon it. It is manifest, therefore, that any new force applied to it, having a component making an oblique angle with c O (Figure 33), must, unless such component pass through the centre of inertia, disturb the equilibrium of the position of the body. In other words, the prolate axis, a b, would be inclined so as to make an angle with c O. The actual direction of the motion would be a resultant of this perturbative action and the existing strain toward accelerated rotation. It is supposable that this strain might be so nearly equal

* I shall employ this principle in explaining the origin and phenomena of vulcanicity in the earth.

to the synchronous tendency that the power overcoming this tendency would only need to be comparatively slight, and that, consequently, the actual movement of the mass would be about an axis very nearly normal to the plane of its orbit, and, on the assumption made, in the direction of the orbital motion. I see no ground for assuming that such a relation of perturbative and synchronizing forces is unlikely to arise in a nebulous spheroid resulting from the spheration of a nebulous ring.

Should the disturbing action be temporary, the body would swing back to the position determined by the original forces; or rather, it would swing past that position and begin an oscillatory movement which would be perpetuated until interfered with by some other external disturbance. It is manifest that this oscillation of the line $a\,b$ might be in any plane. If not exactly in the plane of the orbit, or in a plane at right angles with this, the motion might be resolved into two components, one lying in each of these planes. Thus would arise movements analogous to those known in astronomy as nutations and librations. It must not be supposed, however, that the longer axis of the *figure* would receive the whole of this motion, since attraction toward O, together with intermolecular freedom of motion, would cause this axis to lag behind during every oscillation of the former axis away from the line $c\,\mathrm{O}$. In other words, just so far as intermobility of parts exists, the prolate axis would be maintained in the direction $c\,\mathrm{O}$; and it would be swung out of this direction only in proportion as the mass might have progressed toward a state of rigidity.

According to the conception here set forth respecting the formation of a prolate spheroid, the synchronism of orbital and axial movements might be destroyed only after cooling and contraction should have developed sufficient tendency to accelerated motion to overcome, in conjunc-

tion with any perturbative action, the actions holding the line $a\,b$ in its position. If, while this acceleration is becoming developed, the mass should attain approximate rigidity, the superficial currents before mentioned would be arrested, and would cease to contribute their agency toward an increased rotation of the general mass; but, on the contrary, the crushing process of maintaining prolateness would be greatly opposed, and the prolateness would be correspondingly diminished, together with its resistance to heterochronous rotation.

The conservation of synchronous motions would be promoted by an action not yet mentioned. Conceiving each tidal protuberance to be represented by a point at the apex, it appears that the one on the nearer side by being brought under an increased centripetal force will suffer a tendency to accelerated motion in its orbit. The effect of this would be to set up a retrograde rotary motion in the derived spheroid. On the contrary, the point at the apex of the anti-tide, by being brought under a diminished centripetal force, will suffer a tendency to retarded motion in its orbit. The effect of this will also be to set up a retrograde rotary motion in the derived spheroid. This factor unites with intermolecular friction, cohesion and inertia in delaying the establishment of heterochronous motions.

A rigid body, or any solid body approximately rigid and incompressible, possessing such prolateness as to result in synchronism of axial and orbital motions, could never have this synchronism destroyed except by a disturbance exerted from without. This, therefore, is a relation of orbital and axial motions which ought to result sometimes in the progress of the history whose earlier chapters we are endeavoring to trace. It would be more likely to result in proportion as the process of refrigeration should

be relatively more rapid. This would take place in nebulous masses relatively smaller.

4. *Ultimate Synchronism of Axial and Orbital Motions.*—It should be mentioned in this connection, that synchronous movements having been once overcome, in the early stage, there would be felt a tendency to their reproduction, under certain conditions, during a later stage of development. While the nebulous condition exists, contraction would be rapid and great in amount. The resistance offered by prolateness to the destruction of synchronism, would perhaps, therefore, in all cases, be completely overcome, and a rapid rotary motion would be a nearly uniform incident in the history of cooling. But, as the tidal protuberance, even if solidification should ensue, can never cease to exist, its influence in opposing rapid rotation will never be removed. When, therefore, the rate of contraction and consequent tendency to accelerated rotation has been much reduced by an advanced stage of cooling, or by incrustation or solidification, the resistance of the tidal prolateness, which does not diminish accordingly, must again tend to equilibrate and neutralize the rotating tendency. This effect, upon a globe perfectly solidified, would probably reach a maximum in those cases where fluids like oceans should rest in basins with solid barriers against which the fluid tide could act. Thus the condition of synchronous axial and orbital revolutions is also an incident in the advanced stages of the cooling-history.

5. *Summary.*—We have thus been occupied with the difficult question of the direction and velocity of the rotation which would arise in a spheroid resulting from the spheration of a nebulous ring detached from a central rotating mass. The conclusions reached may be summarized as follows:

(1.) Rotation would arise with the process of sphera-

tion, and its axis would most probably be at right angles with the plane of the nebular equator.

(2.) The direction of the rotation would be determined by the relation of the velocities of the outer and inner zones of the ring.

(3.) If all parts of the ring rotated with nearly the same angular velocity, the resulting rotation in the spheroid would be direct.

(4.) If the inner zone rotated with increased velocity, in accordance with the law of equal areas, the rotation would be retrograde.

(5.) Friction and cohesion and mutual attraction of parts would have a tendency to equalize angular velocities, and thus to create a strain toward direct motion.

(6.) If this strain were unequal to the tendency toward motion under the law of equal areas, the rotation would be *retrograde;* if it equalled that tendency there would be *no* rotation; if it exceeded it, the rotation would be *direct.*

(7.) The strain toward direct motion would be least when the nebulous matter is tenuous, for then friction and cohesion would be least, and the influence of gravitation would be least felt. The strain toward retrograde motion would be greatest when the ring is widest, for then the acceleration of the inner zone is greatest. The conditions of least strain toward direct motion and greatest toward retrograde motion would concur in the earlier annulating stage of the nebula.

(8.) The strain toward direct motion would be greatest when the nebulous matter is most dense, for then friction and cohesion would be greatest, and the influence of gravitation would be most felt. The strain toward retrograde motion would be least when the ring is narrowest, for then the acceleration of the inner zone would be least. The conditions of greatest strain toward direct motion

and least toward retrograde motion concur in the later annulating stage of the nebula.

(9.) The rotation, if direct, would at first probably be synchronous with the orbital revolution, and the derived spheroid would be prolate. This prolateness would tend to persist. (*a*) In consequence of the imperfect intermobility of parts in the spheroid. (*b*) In consequence of an adjustment of parts having different densities, so that the most and least dense would be ranged about the poles of the prolate axis.

(10.) The progressive contraction of the derived spheroid would result in a perpetual tendency to rotate more rapidly; and this tendency might overcome the tendency to synchronous movements. This would be the more likely as the latter tendency would diminish with the increase of the square of the interval between the centres of gravity of the derived and original masses.

Memorandum.—This interval would increase. (*a*) By the progressive shrinkage of the central mass. (*b*) As a consequence of the diminished centripetal force. (*c*) As the result of any eccentric motion which may, in some cases, have been imparted to the derived mass at the epoch of its separation from the primitive mass.

(11.) In a derived spheroid possessing great, but unequal, intermolecular mobility, the establishment of superficial currents, gradually deepening and involving the whole mass, would tend to destroy primitive synchronous movements.

Memorandum.—The prolateness of the derived mass would, however, be maintained, and would diminish only in proportion as its rigidity should increase.

(12.) Perturbative action having a component making an oblique angle with the prolate axis might overcome any preponderating tendency to synchronous motions.

(13.) In a *rigid* prolate body synchronously rotating,

only external perturbative action could ever destroy the synchronism.

(14.) Rotation would also be caused by the inevitable ultimate coalescence of the two or more masses into which it is supposable that an unstratified nebulous ring might, in some instances, be separated. The discordant positions of the rotational axes resulting from this cause are, however, not distinctly apparent among the phenomena of the solar system.

(15.) Synchronous motions would result again, in the ulterior history of the derived spheroid, through the continued action of tidal friction. This result, though favored by the existence of fluids on the surface, would not be permissively conditioned upon it, since all tidal motions in a spheroid whose constituent parts are not perfectly free to move, are, by so much, constrained in the direction opposed to those motions, the tidal effects are delayed and the tidal action becomes thus a constant effort to rotate the spheroid in the direction of the tidal progress, that is, in a direction contrary to the normal rotation of the spheroid.*

6. *Arrangement of Heavier Matters on the Derived Spheroid.*—In all stages of the derived spheroid there would be a tendency of the heavier parts to accumulate on the side nearest the central attractive body. There may be a condition of matter in which diversified densities have not been attained. There is also, probably, a stage of nebulous history in which the intermobility of parts prevents adjustment of portions in accordance with densities. But assuredly, a time sooner or later arrives when diversity of densities not only exists, but the conditions are such that the positions of the parts must be determined by their relative densities. While synchronistic motions exist, there will be two forces acting toward the determi-

* The subject of tidal action will be resumed and studied in greater detail in connection with planetary evolution.

nation of those relative positions. One is the central attraction toward the centre of orbital motion; the other is the centrifugal tendency resulting from the orbital motion. The nearest parts experience most of the centripetal tendency, and the remotest parts, most of the centrifugal tendency. The centripetal force tends to bring the denser parts to the nearer side, and the centrifugal force tends to transfer them to the remoter side. Unless the excess of the centripetal force on the nearer side exactly equals the excess of the centrifugal force on the remoter side, the heavier parts must tend toward one extremity of the prolate axis. Whichever be the side toward which they settle, the resulting distribution of the matter must constitute a resistance to the disturbance of synchronistic motions.

The factors entering into a determination of the question to which side the heavier parts would tend are, the mass of the central body, the distance between its centre of gravity and that of the derived spheroid, the length of the prolate axis of the derived spheroid and the velocity of motion in its orbit.

In any particular case, where the mass of the central body and the length of the prolate axis remain constant, the relation of the differential centripetal and centrifugal forces to each other will vary, on condition of uniform angular velocity of rotation, with the distance between the centres of gravity of the two bodies. But the differential centrifugal tendency, on the conditions assumed, remains constant.* On the contrary, since the centripetal

* The centrifugal tendencies at the nearer and remoter poles of the prolate axis being represented by F' and F'', and the distances of these poles by d' and d'', we have for the angular velocity θ, by the principles of mechanics, $F''-F' = d''\theta^2 - d'\theta^2$. Now suppose the spheroid to be placed at a different distance from the central body, so that $d' = d' \pm n$ and $d'' = d'' \pm n$. Letting f' and f'' represent the centrifugal tendencies at the poles of the prolate axis, in the new position, we have, for the same angular velocity as before, $f''-f' = (d'' \pm n)\theta^2 - (d' \pm n)\theta^2 = d''\theta^2 - d'\theta^2 = F''-F'$. Hence the differential centrifugal tendency remains constant.

force varies inversely as the square of the distance, the differential centripetal tendency increases with the distance between the two bodies. Hence if, at any distance, the differential centripetal and centrifugal tendencies are equal, at a less distance the centrifugal would preponderate, and at a greater, the centripetal would preponderate. Where the orbital motion at different distances is in conformity with Kepler's third law, the angular velocity, and hence the differential centrifugal tendency would be increased with shortening of the distance; and accordingly, the differential centripetal and centrifugal tendencies would not diverge as rapidly (with a given rate of change in distance), as when, according to our first supposition, the angular velocity remains constant.*

7. Orders of Nebulæ.—Let us remember that our speculations thus far concern nebulæ; and that the segregation of parts results in a system of nebulous masses, each of which in turn may be destined to repeat the evolutions of the parent nebula. Consider then, one of these

* The eqnation of differential centripetal and centrifugal tendencies presents the following relation among the values involved:

Let g = gravity at the central body's surface, assumed to be a sphere without rotary motion.

d' and d'' = distances from centre of gravity of the central body to the nearest and remotest poles of the prolate axis.

v' and v'' = the linear orbital velocites respectively of these two poles.

R = radius of central sphere.

Then the condition of eqnal differential centripetal and centrifugal tendencies gives

$$\frac{v''^2}{d''} - \frac{v'^2}{d'} = g\frac{R^2}{d'^2} - g\frac{R^2}{d''^2}.$$

But since $v'^2 = \frac{v''^2 d''^2}{d'^2}$, we have

$$\frac{v''^2 d''^2}{d'^2 d''} - \frac{v'^2}{d'} = g\,R^2\left(\frac{1}{d'^2} - \frac{1}{d''^2}\right).$$

Whence

$$v' = \frac{R}{d'}\left[\,g(d'' + d')\,\right]^{\frac{1}{2}}.$$

Also, since the angular velocity $\theta = \frac{v'}{d'}$,

$$\theta = \frac{R}{d'd''}\left[g(d'' + d')\right]^{\frac{1}{2}}.$$

partial nebulæ. Though presenting but a small disc, at the enormous distance from which we gaze upon it, we must suppose its diameter greater than that of our solar system. It is still in large part an incandescent vapor. There was a time when the matter of our solar system was one of these partial nebulæ, or perhaps an original growth which had never attained larger dimensions, or perhaps again, one of the segregated masses of a non-rotating nebula. Many of the stars in our firmament represent other nebulæ of the same order, out of which have emerged the stars and the planetary systems which probably circle around them. It was the speculation of Kant, and the original conception of Sir William Herschel (though he did not so distinctly enunciate the agency of rotation) that at periods incalculably remote, an enormous system of partial nebulæ had issued from that grand universal nebula which contained all the matter of our firmament of stars and planets. This firmament, as they thought, was possibly once a nebula, like those other thousands of nebulæ which we believe to have advanced varying distances on the way to completed stellation. Kant conceived that it performed then a stupendous gyration about an axis. Even now, that gyration should be continued. The idea is not entirely fanciful; for astronomers have shown that all the stars, as a rule, are actually in motion; and Maedler believes that he has rendered it probable that our sun has Alcyone in the Pleiades for the centre of its orbit, and consumes 180 millions of years in completing a single revolution. If a nebula requires 180 millions of years for a single rotation, what change of position could we expect to detect in the brief interval since the construction of Sir William Herschel's great telescope?

It must be soberly said, however, that there is comparatively little ground for the opinion that our entire firmament is now in a state of gyration about a common

centre. In such case there would be more consentaneousness in the movements which have been actually traced among the fixed stars. There is no conceivable system of relative positions and velocities about a common centre which would develop the seemingly sporadic movements which we witness. Undoubtedly every star is in motion; and undoubtedly every star's motion is in obedience to the laws of central forces. Undoubtedly the sun and solar system are moving majestically across the spaces which separate star from star. It is shown also that many couplets and larger groups of stars are physically connected; and that most of the stars in certain regions of the heavens possess a common motion; but we have not, as yet, good inductive ground for affirming a common rotary motion of our firmament, or its derivation, by the annulation process, from a general firmamental nebula. There is more ground for the belief that each star is the residual centre of a distinct nebular mass, by whatever process isolated. We may therefore reasonably proceed to contemplate the evolution of a solar nebula, regardless of the nature of its origin or previous transformations. This brings us to the question of the primitive history of a solar system.

But we pause here in the midst of our speculations. The very firmament is careering in infinite space, while we ponder on its constitution and history or turn to our material occupations. Our comfortable homes, while we dine or sleep, are rolled through space at the rate of seven hundred miles an hour by the diurnal rotation of the earth. During the same time they are transported sixty-eight thousand miles by the movement of the earth in its orbit. Then the sun, with his entire family of planets, is sweeping through immensity, toward the constellation Hercules, with a velocity which, if equal to that of Arcturus, is two hundred thousand miles an hour. And lastly, there must

be some common motion of translation of the whole inextricable maze of moving stars, and with a velocity to which fancy may assign what rate it pleases without restraint from science. This mighty waltz of cosmic dancers is joined by the gauzy nebulæ, animated also, like our firmament, by their own internal motions. In the midst of this universe of seething movements is our appointed home. The mind uplifted in the effort to contemplate them and grasp their method, grows giddy and impotent. How sublime these activities! To what a numerous and lofty companionship does our little planet belong! Hard it seems to be imprisoned here while the realm of the universe tempts us to its exploration. How can a human soul content itself to roll and whirl through space during its mortal days, and eat and sleep and trifle, like rats in a ship at sea, without wondering where we are and whither we are bound?

PART II.

PLANETOLOGY.

CHAPTER I.

ORIGIN OF THE SOLAR SYSTEM.

Theoriarum vires, arcta et quasi se mutuo sustinente partium adaptatione, quâ, quasi in orbem cohærent, firmantur.*—BACON.

Erst, space was nebulous.
It whirled, and in the whirl, the nebulous milk
Broke into rifts and curdled into orbs—
Whirled and still curdled, till the azure rifts
Severed and shored vast systems, all of orbs.—DAVID MASSON.

I HAVE presented, in the preceding chapters, some of the evidences of the wide diffusion of world-stuff through space. We have no warrant whatever for affirming its diffusion "through infinite space"; nor can we rationally speak of any particular condition of this matter at any absolute "beginning." Nor can we affirm that it was distributed "uniformly"; nor that its tenuity was any number of thousand times "greater than that of hydrogen." It suffices to recognize the evidence that the cosmic matter which we now see aggregated in worlds existing in various stages of development from a conceivable and rational starting point, was once widely diffused, and probably cold; and that by the mutual attractions of particles and masses, much of this matter became gathered into aggregations of vast magnitude.

I have also attempted to show that the further operation of gravity would tend perpetually to the further aggregation of these masses, and that their collisions would result in the development of intense heat. I have

*The strength of theories is established by their compact and mutually sustaining coadaptation of parts, by which they cohere as in an arch.

shown that rotary motion must have been also a result of such collisions; and must also have been generated by mutual attractions without the occurrence of collision. I have traced the further consequences of the rotation of a heated globe of nebulous matter, and have pointed out the necessity, in some cases, of a process of annulation, and the subsequent gathering of the rings into spheroidal masses rotating on their axes and revolving in orbits about the residual mass.* The process, as described, results in breaking up a great firmamental nebula into a large number of partial or solar nebulæ; and it is one of these, or at least a nebula of this order of magnitude, which we are to follow further in the course of its evolution.

It is not implied that all solar nebulæ have been thus derived. It cannot be doubted that many nebulæ are of magnitudes so small comparatively that they condense directly into suns and planets. They have never been of any higher order than solar nebulæ. Whatever its antecedent history, it is the solar nebula to which attention is now directed.

Being a nebulous mass essentially identical, except as to magnitude, with the firmamental nebula which we have been considering, it is evident that all its nebulous history must be essentially such as we have already traced. It only remains, therefore, to continue to follow the evolution in a case in which a nebulous globe condenses directly to the solar and planetary conditions. What needs to be said to make this part of the process plain to the reader can perhaps be best presented in the form of a citation of actual phenomena which find their best explanation in a nebular evolution; and then a discussion of the various

*Should the reader feel interested in further views on the origin of clusters and nebulæ, he may consult memoirs of Prof. Stephen Alexander in Gould's *Astronomical Journal*, vol. ii, 1852; as also those of Sir William Herschel as cited in Part IV, ch. iii, § 2, of the present work, and the coincident views of Arago in *Astronomie populaire*.

objections which have been urged against the theory by various classes of persons.

§ 1. VERIFICATION OF THE NEBULAR THEORY FROM FACTS.

I. *Observed Phenomena of the Solar System which accord with the requirements of the Nebular Theory.*

A. DEMONSTRATIVE PHENOMENA.

(See Works on Astronomy.)

1. The planets all move in their *orbits* in the same direction.

2. The sun rotates on his axis in the same direction as the planets revolve in their orbits.

3. All the planets, except Uranus and probably Neptune, rotate on their *axes* in the same direction.

4. All the satellites revolve in their *orbits* in the same direction, except those of the planets Uranus and Neptune.

5. The moon rotates on its *axis* in the same direction; and no satellite is known to rotate in the opposite direction.

6. The planes of all the planetary orbits are nearly coincident.

7. The plane of Neptune's orbit is almost exactly coincident with the invariable plane of the solar system. (See § 3, 1.)

8. The planes of all the planetary orbits in the course of their secular oscillations approach nearly to coincidence with the invariable plane; and the orbits of Venus, the Earth and Mars attain to complete coincidence. (See § 3, 1.)

9. The planes of the secondary orbits are all nearly coincident with the planes of the equators of their primaries.

10. The plane of the sun's equator is nearly coincident with the invariable plane of the solar system.

11. The sun is the centre of motion of all the planets.

12. Every system of satellites has one primary for its centre of motion.

13. The orbital paths of the planets and satellites vary but little from circles.

14. The larger planets have the greater number of satellites because greater mass would prolong the period of mobility of parts, and thus the possibility of annulation.

15. The angular and also the actual velocities of the planets and satellites in their orbits increase with the decrease of their mean distances from their centres of attraction.

16. The Saturnian system still retains an example of the ring-condition.

17. The Earth furnishes evidence of intense internal heat, and other evidences of a general temperature in ancient times, sufficiently high to fuse rocks at the surface. (See chap. III, § 1, 1.)

18. The superposition of unaltered sedimentary rocks over metamorphic sedimentary rocks implies a process of cooling. (See works on Geology.)

19. The animal and vegetable forms fossilized in the older rocks prove an ancient higher temperature for the terrestrial climates. (See *Sketches of Creation* and works on Geology.)

20. The oblateness of the other planets implies a former state of fluidity in them.

21. The crater-like forms seen upon the surface of the moon indicate a former intensity of igneous action. (Chap. III, § 2, 3.)

22. The absence of air and water from the moon indicates a state of complete refrigeration. (Chap. III, § 2, 5.)

23. The cloud-enveloped condition of Jupiter, together with some indications of inherent luminosity, implies a temperature higher than that of the earth; and this may be supposed inherited from a past still more highly heated condition. A less advanced stage than that attained by the earth would be attributable to the vastly greater mass of matter in that planet, which would demand vastly more time to reach a cooled and habitable condition. (Chap. III, § 5.)

24. The substances which enter into the constitution of the sun are the same as those in the earth. (See Young on *The Sun;* Secchi: *Le Soliel;* Schellen: *Spectral Analysis*, etc.)

25. The composition of meteorites coming from the planetary spaces is terrestrial, and points to the general inference that all the bodies occupying the planetary spaces have the same composition as the earth and the sun. (See Meunier: *Le Ciel Géologique*, and works on meteorites.)

26. The planets and satellites all move about their central bodies with velocities so varying with the distance that the radius vector of each body describes equal areas in equal times.

27. Our satellite always turns the same side toward the earth; and so far as we know, all the satellites of our system turn always the same side toward their primaries.

28. The sun still exists in a nebulous condition so far as exposed to our inspection.

B. PHENOMENA PROBABLY CONFIRMATORY.

29. The period of rotation of Saturn's rings is less than the axial rotation of the planet.

30. The orbital velocities of the planets conform to the third law of Kepler instead of being in the ratio of the squares of the mean distances from the sun. (See § 2, Objection 4.)

31. The ratio of the radii of gyration of the successive spheroids in the development of the Jovian system, to the actual mean distances of the Jovian satellites, is less than the corresponding ratios in the original planetary spheroids to the actual mean distances of the planets from the sun.

32. The rate of axial rotation as we recede from the centre of motion of the system toward the periphery is increasingly more rapid (p. 165). The only exception is Jupiter, which rotates 36° an hour, while Saturn rotates only 34°.5 an hour. (See Part I, ch. ii, § 4, 2.)

II. *Observed Phenomena not belonging to the Solar System which accord with the requirements of the Nebular Theory.* (See Part I, ch. ii.)

33. The nebulæ and other cosmic bodies exist in a nebulous state.

34. The ring condition actually exists in certain nebulæ.

35. Spiral and other nebulous forms indicate a state of rotation.

We may cite in addition the brilliant experiment of Plateau.*

All the foregoing phenomena observable within the solar system are, at least to the 28th,† so obviously conformable to the requirements of the nebular theory that probably no reasonable person will maintain that they present any difficulties. Now what must be said in view of such a catalogue of coincidences? They show at least, that all parts of our system must have had a common origin and a

* J. Plateau: *Memoire sur les phenomènes que présente une masse liquide libre et soustraite à l'action de la pesanteur*, Nouveaux memoires de l'Académie de Bruxelles, xvi. 1843, translation, *Experimental and Theoretical Researches on the Figures of Equilibrium of a Liquid Mass Withdrawn from the Action of Gravity*, etc., Smithsonian Reports, 1863.

† Prof. Stephen Alexander enumerates 62 "consistencies" or confirmations of the nebular theory (*Smithsonian Contributions* xxi, Art. I, pp. 80-91).

common history. If our earth has had a cosmic history, then that history involved all the other bodies of our system. Unless we choose to abandon all scientific method, and dogmatically assert that each world is the product of immediate creation, and deny that the plan which embraces their forms and movements shows any physical relation among them, we must seek for a theory of their past history which will coincide in all these twenty-eight particulars with the facts of observation. But a physical relation exists among all the parts of the solar system in human times; they are acting mutually upon each other; new positions and conditions are daily arising out of these mutual actions. We have seen a brief chapter of cosmical history enacted during the period of our observations; and the denial that this history stretches back into prehistoric and remoter times is a folly only equalled by that of a man who should stand on the banks of the Mississippi at New Orleans, and declare that the stream had no existence northward beyond the range of his vision. The parts of the solar system are physically connected in human times; and he who would deny that the history of such connection stretches into a remote past is incapable of reasoning on the subject.

Now, if the real history whose outcome we look upon is a history of physical actions and reactions, what conception can be formed of the particular nature of that history which will be more conformable to the leading facts of observation than the conception of an original nebula, rotating and cooling, and evolving progressively the incidents of such a process? With so extended a catalogue of coincidences, a mere hypothesis ought to be regarded as a highly probable representation of the truth; unless some grand phenomenon remains to be accounted for, or some strictly crucial test dissipates the accumulated probability in its favor.

I hear it said that these grandly outlined events are only a dream — a poetic creation, without the possibility of a demonstration. Well, if no more could be said, I am prepossessed by them, as the best and most plausible conjectures which could be made by the wisest of men. Until some objector can put forth a more probable conception of that past history which has been so real, I deem it wise to pay respect to a conception which has been growing in esteem for three quarters of a century. Let it be a mere hypothesis; it may be one ripened into an imperishable doctrine. Gravitation was a mere hypothesis once — and once even an abandoned hypothesis. That the planets move in ellipses was Kepler's hypothesis; but now it is demonstrated. Is it said, the nebular hypothesis cannot be demonstrated? It is all but demonstrated to-day; and he who doubts is more credulous than he who believes. It is all but demonstrated by the three dozen coincidences which I have enumerated. And it is all but demonstrated by the rigorous processes of mathematics which so long since gave a rational basis to Kepler's laws.

Yet, in the presence of so many coincidences and confirmations; with the great weight of almost unanimous scientific opinion for an indorsement, we find such a judgment as the following on record in a work which is still recent: "We are obliged to conclude that the nebular theory lacks all the elements of credibility. It is at variance with astronomical facts. It is destitute of philosophical consistency. It assumes everything that ought to be demonstrated. It deals in glittering generalities where it ought to go into minute details. It ignores the mathematical relations of forces and effects. In fine, its data are intangible, incongruous and impertinent to its conclusions. Never in the history of science was theory more pretentious. Never did theory less justify its preten-

sions."* This language is emphatic and unreserved. Every word deserves to be italicised. This is the daring indictment drawn up against the good judgment of such astronomers and physicists as Laplace, Sir John Herschel, Helmholtz, Mayer, Tyndall, Sir W. Thomson, Clerk Maxwell, Clifford, Croll, Huggins, Lockyer, Arago, Oersted, Becquerel, S. C. Walker, Benjamin Peirce, B. A. Gould, D. Kirkwood, J. C. Watson, G. Hinrichs, D. Trowbridge, S. Newcomb, C. E. Young, J. E. Hilgard, Joseph Leconte and a host of other names of similar authority in these and other departments of natural science. How superior must be the knowledge and the penetration of the individual who could bring such an indictment against such an array of honored names. And how clear and demonstrative the apprehension of the grounds of an indictment presented with such unruffled assurance of infallibility.

§ 2. OBJECTIONS BASED ON RELATIONS OF PLANETARY MOTIONS.

Let us now examine the phenomena which by one and another have been cited as incompatible with the nebular theory.

1. *Retrograde Motions.*†—The satellites of Uranus revolve in a plane which makes an angle of 98° with the plane of the ecliptic. That is, the system is tilted up until it is 8° beyond a right angle with the ecliptic, and the satellites thus have an apparent retrograde motion. Similarly, the

* Rev. W. Slaughter: *The Modern Genesis* p. 290. We might offset this bold arraignment by the following passage from an authority of high and recognized standing as a logician: "There is thus in Laplace's theory," says John Stuart Mill, "*nothing hypothetical*; it is an example of *legitimate reasoning* from a present effect to its past cause, according to the known laws of that cause; it assumes nothing more than that objects which really exist, obey the laws which are known to be obeyed by all terrestrial objects resembling them" (*System of Logic*, Am. ed., p. 299.)

† M. Faye, *Comptes Rendus*, xc, pp. 566-71, March, 1880; Rev. W. B. Slaughter: *The Modern Genesis*, 103-109.

plane of Neptune's satellite is tilted over 145°, so that it seems to have a retrograde motion in an orbit inclined 35° to the plane of the ecliptic. Now, nothing is more natural than to suppose that a partial inversion of these systems has taken place. These inclinations, in fact, are only extreme cases of the inclination which characterizes all the orbital and equatorial planes of our system. The satellites of Saturn have generally an inclination of 28°, and one of the Asteroids has an inclination of nearly 35°.

(1.) It is entirely conceivable that both the Uranian and Neptunian systems should have suffered an overturn through the influence of some powerfully attracting body passing in the neighborhood. If this occurred before the planetary nebula had commenced annulation, then the motions of its later-formed satellites would conform to the plane of the planetary rotations. If it occurred after the satellites were formed, their orbits might depart very far from the equatorial plane of the planet. It is even conceivable, in this case, that the planet's rotary motion might be direct while the orbital motions of the satellites are retrograde. The influence of such disturbing body may also have been felt by the Saturnian system, which shows an extraordinary inclination, while the planets successively more remote have been successively more disturbed.

The accompanying figure (Figure 33) will illustrate a possible method of the overturn of a system after the formation of the satellites. It represents a planet in its orbit, and surrounded by the orbit of one of its satellites. The latter orbit is originally coincident with the plane of the planetary orbit as shown in $B N_2 A N$. But suppose when the satellite is at A, an attractive influence to be felt from the direction C A; one component of this force would act in the direction A G, in the plane of the orbit, and would not alter the inclination of the orbit; but the

other would act at right angles with this, in the direction A F, and would tend to carry A toward F, but the attraction of the planet would bring A toward the position A′. The satellite would pass on in its orbit, but upon its return to the vicinity of the position A, a further impulse would be felt. This would be repeated again and again,

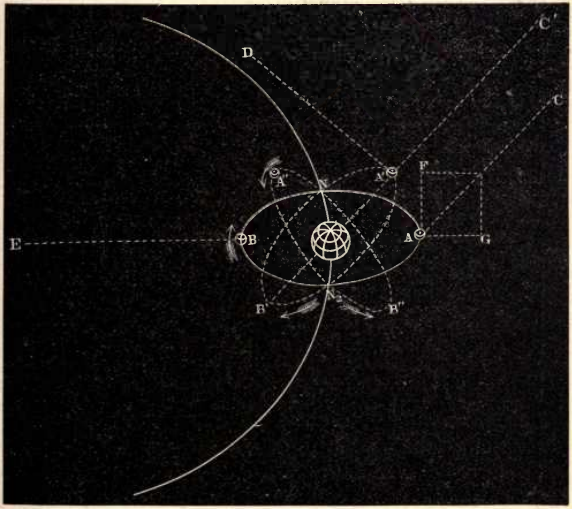

Fig. 34. Inversion of the Orbit of a Satellite.

as long as the disturbing body should remain in the same general direction. It is true that the satellite would be attracted throughout its whole course, and at B the effect would be a partial restoration of the original position of the orbit; but the influence at B would be less than at A,

because its distance from the disturbing body is greater; and hence the residual effect upon A would be due to the *difference* of the attractions in the two positions A and B.

It is necessary to trace this effect somewhat farther. Had the satellite no inertia, the disturbing influence would turn its orbit only so far as to bring the plane into coincidence with the direction of the influence C′ A′ B′. But the momentum acquired will carry the satellite beyond that point. If the influence still persists, the orbit will return and will thereafter oscillate slightly on both sides of the plane of coincidence. But if the influence disappears, or if an influence from another direction D A′ arises, the motion of the orbit may continue until its angle with the plane of the planetary orbit exceeds a right angle by any amount.

Now, suppose, before the satellite's orbit has been changed in position, an observer on the earth looking from the direction E, sees the satellite at B, moving in the direction of the arrow; call this direct motion. But suppose that afterward, when the orbit has been tilted so that the satellite on its passage through the point A″ nearest the earth shall again be seen from the direction E, it is evident that its apparent motion (in the direction from the node N to the position A″) will be the reverse of its former motion. This would be retrograde. But the satellite has continued to revolve in the same orbit and in the same direction, that is from the corresponding positions B, B′ and B″ toward the node N, and from N toward A, A′ and A″, which represent the same point in different positions of the orbit

One thing more; the action of the disturbing force is not likely to be exerted only in a direction at right angles with the line joining the nodes N and N_2, of the satellite's orbit. One of the effects, therefore, will be to wrench the orbit out of its position; that is, to change the position of

the hinge-line N N_2 on which it turns in suffering a change of inclination. Or, in astronomical language, the longitude of the ascending node N would be changed; and when once a motion from its primitive position should be begun, nothing but an exact equilibrating force would ever stop it. Thus the longitudes of the nodes of all the orbits of our system are changing their positions. A similar action would change the position of the apsides in reference to the nodes.

(2.) I have already indicated (p. 120) another possible cause of such an irregularity, in the coalescence of the two or more spheroids into which a nebulous ring may have been separated. If the resultant planet, by the collision of these partial masses, has had its axis tilted over, its whole system of satellites must be correspondingly tilted.

(3.) In discussing the direction and velocity of rotation acquired by a derived nebulous spheroid, I have pointed out the conditions under which certain relations of density, distance from the centre of the nebular mass, breadth of ring and velocity would result in retrograde motion. Such motion would be a normal phase in the earlier stages of the evolution of a nebula of a certain magnitude. It might seem, therefore, that no occasion exists for seeking further for the cause of retrograde motions in our system. But it must be borne in mind that the rotations in the Uranian and Neptunian systems are not completely retrograde, but lie in planes having high angles with the plane of the solar system. That of the Uranian system is, indeed, but little less than a right angle. But the cause here referred to would produce retrograde motion very nearly in the plane of the solar equator. For this reason I have not placed this explanation in the front. There is room to suppose that our solar nebula was not of such magnitude as to develop retrograde rotations in its earlier stages; and that the partial retrograde motions which we witness are

due to the operation of some other cause. The condition of things seems very strongly to suggest the action of some overturning influence which might cease with any assignable degree of inclination.

(4.) M. Faye, who accepts in its general features a nebular history for our solar system, has presented a modification of the theory of Laplace,* in which he expresses the opinion that retrograde motions would normally prevail in the earlier stages of the evolution, and direct motions in the later. These views, as well as the similar ones of Professor Hinrichs, are cited on a previous page. It will be noticed, however, that their theories require the primitive retrograde motions to take place nearly in the common plane of the solar system. The same objection therefore rests against them as against the theory which connects direct rotations with increased density of the nebula.

It may never become possible to demonstrate by which of the foregoing or other means a retrograde motion became established in the remoter parts of the system. However, unless our reasoning is entirely at fault, it appears that more than one possible means has existed for producing retrograde rotations in one part of the system, and direct rotations in another. The state of the facts is such, at least, that the existence of retrograde motions in the remoter regions cannot reasonably be assumed as a fatal or even a damaging circumstance in nebular cosmology.

2. *The Periodic Times of the planets are longer than the Nebular Theory allows.*† — The periodic times are of course inversely proportional to the angular velocities; but, as before stated (p. 109) the angular velocities are

* M. Faye, *Comptes Rendus*, xc, 637, March 22, 1880.

† D. Trowbridge, *Amer. Jour. Sci.* II, xxxviii, 3, 4; Rev. W. B. Slaughter; *The Modern Genesis*, ch. v.

inversely proportional to the squares of the radii vectores. That is, the time of rotation of the nebulous spheroid would be proportional to the square of its equatorial radius. But, by Kepler's third law, the actual periodic times of the planets are proportional to the square roots of the cubes of their mean distances from the sun.* The periodic times of the planets are therefore greater than the theory allows.

Now, I think it may be shown that such a lengthening of the periodic times is exactly what the theory requires.

(1.) Let A, Figure 35, be the last formed planet at any epoch, revolving about the solar nebula in such an orbit and with such a period as would be required by the nebular theory. Let C D E represent the outer periphery of the

* That is, while the nebular theory requires

$$\theta : \theta' :: r'^2 : r^2 \text{ (p. 109)},$$

or what is equivalent,

$$t : t' :: r^2 : r'^2,$$

the actual motions of the planets give, by Kepler's third law,

$$t^2 : t'^2 :: r^3 : r'^3,$$

or

$$t : t' :: r^{\frac{3}{2}} : r'^{\frac{3}{2}},$$

t and t' being the times of revolution of the nebulous disc in two different states of contraction, and therefore the theoretical periodic times of two planets resulting from rings detached in those states, and r and r' the radius vector in the two states, or of the two corresponding planets. Now, if t' is less than t, then r' is less than r, and the ratio $r^2 : r'^2$ is greater than the ratio $r^{\frac{3}{2}} : r'^{\frac{3}{2}}$; which means that t' when used for the periodic time of a planet, is greater than t' when used to express the time of rotation of the nebulous spheroid when having a radius r'. Each planet, therefore, moves too slowly in reference to planets exterior to it. In other words, the progressive acceleration has been less than is required by the principle of equal areas.

Professor Hinrichs has attempted to show analytically that the nebular theory involves a passage from the primitive velocity into the rate of motion expressed by Kepler's third law (*Amer. Jour. Sci.* II, xxxix, 140-1).

It is an error of some of the critics of the nebular theory to assume that the oblateness is proportional to the *angular* velocity, regardless of the value of the radius of rotation. Oblateness depends on centrifugal tendency, and this varies directly as the product of the equatorial radius of the spheroid into the square of the angular velocity, or, in other terms, directly as the square of the linear velocity and inversely as the equatorial radius. Rev. Mr. Slaughter in proving that the observed rotational velocity of Neptune is too small to have produced a ring-making degree of oblateness when the nebulous spheroid extended to Neptune, compares only angular velocities (*The New Genesis*, 85-87). The same error is repeated in reference to the other planets.

residual central mass at this time. Its centre of gravity being at S, the attraction of the whole mass constitutes the central force which determines the velocity of A in its orbit. In process of time another ring is detached, which gathers itself into another planet B or B′. The residual nebula is now shrunken in volume to the periphery F G H, and is diminished in mass by the whole amount of the

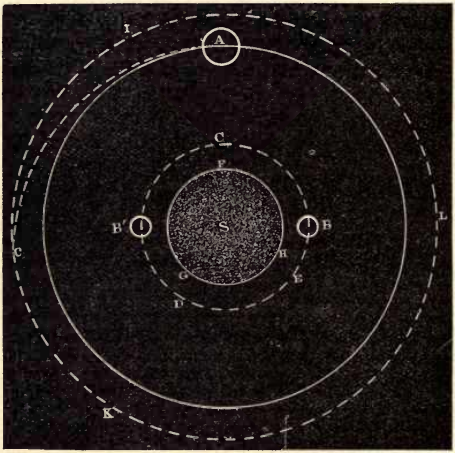

FIG 35.—PROCESS OF LENGTHENING THE PERIODIC TIME, AND ACQUIRING AN ELLIPTIC ORBIT.

planet B. The mass B no longer constitutes a part of the mass whose attraction determines the velocity of A. The mass B, in certain situations accelerates that velocity, and in others, retards it. Its influence has become practically null. But now the diminished mass whose centre of gravity is at S exerts a diminished centripetal force on A.

The planet A, therefore, must recede from S, and move with diminished velocity in order that a diminished centrifugal force may still equilibrate the diminished centripetal force. It is perfectly obvious that the central mass which determines a certain velocity in a circum-rotating body, cannot determine an equal velocity when its mass is diminnished by the separation of another planet; and it is equally evident that the separated planet can contribute nothing permanently to the preservation of the former velocity of rotation.

It must be remembered, however, that a resisting medium would neutralize a portion of the centrifugal tendency of the planet A, and thus slacken its motion without the necessity of a retreat from S. If there were no indication that such retreat has taken place, we would be at liberty to assume that the loss of centrifugal force by ethereal resistance had been just equal to the loss of centripetal force by diminution of the mass S. But I think it will soon appear that these two influences were not equal.

(2.) It seems probable that a most important influence was exerted upon the behavior of the spheroid by the enormous increase of density toward the centre. I have already directed attention in a general way to the necessary existence of such increase of density, but we are able to adduce the results of some calculations in reference to the density of the solar nebula.* If we assume that the oblateness of the spheroid remained nearly the same throughout the history of planet-making, and that in all its parts the centrifugal force was equal to the force of gravity, the following table will show the densities of the equatorial portions at the time of the disengagement of the several planetary rings:

* D. Trowbridge, *Amer. Jour. Sci.*, II, xxxviii, 353-4, Nov., 1864.

Mercury	27.10000000
Venus	3.10700000
Earth	1.00000000
Mars	0.23440000
Asteroids	0.01976000
Jupiter	0.00311300
Saturn	0.00037310
Uranus	0.00003234
Neptune	0.00001485

The calculation shows that the density of the Mercurial ring was 1,825,000 times as great as the density at the outer periphery of the Neptunian ring.* As the disengagement of planetary rings continually diminished the nebular mass, it diminished the power of the central attraction to maintain its high primitive density or tension, and we must therefore conclude that before the abandonment of the Neptunian ring the density at the distance of each of the future planets was greater than the above table shows.

The same general conclusion is indicated by a calculation of another sort, which shows that the radius of gyration of the solar nebula always bore a small ratio to the equatorial radius. In the following table the first column of numbers gives the length of the radius of gyration of the nebular spheroid at the time of separation of each of the planetary rings, and the second column gives the equatorial radius of the spheroid at the same epochs, assuming this to have been the same as the mean planetary distances at the present time.

*It results from an investigation made by J. H. Lane on the necessary density of the sun's interior, on the supposition that it is composed of gases like hydrogen or atmospheric air, that such density at the interior must be of some value ranging from 7.11, about the density of cast iron, to 28.16, which is one-third greater than the density of platinum (J. H. Lane, *Amer. Jour. Sci.*, II, l, 63, 64). According to a law formulated by Legendre and adopted by Laplace, the earth's density, which is 2.55 at the surface, is 8.5 at the mid-radius and 11.3 at the centre.

The mean distance of the earth is taken at 92⅓ millions of miles.*

	RADIUS OF GYRATION.	EQUATORIAL RADIUS.
Mercury	454,000	37,750,000
Venus	725,600	66,750,000
Earth	925,200	92,333,000
Mars	1,269,000	141,000,000
Asteroids	2,145,000	254,000,000
Jupiter	3,187,000	480,000,000
Saturn	5,022,000	881,000,000
Uranus	8,480,000	1,771,000,000
Neptune	11,870,000	2,775,000,000

This table shows that the radius of gyration was always remarkably short compared with the equatorial radius of the spheroid. As the radius of gyration is the distance of the centre of inertia from the axis of rotation, it follows that the greater portion of the mass of the nebula was always condensed about the centre. It is probable that when the Neptunian ring was abandoned, more than half the entire mass of the solar nebula was within the limits of the future orbit of the earth, and the greater part of this portion was within the future orbit of Mercury.

To make the supposed facts clearly intelligible, let S, Figure 36, represent the centre of the nebulous spheroid at the time of the disengagement of the Neptunian ring, S N the equatorial radius, S K the radius of gyration, S M the radius of the future orbit of Mercury, and S E that of the earth. Now S K being represented by a quarter of an inch, S M is 3.2 times as great, S E, 7.7 times as great, and S N should be 23.4 times as great. That is, S N should be represented by 5⅞ inches. Or, if S N is represented by six inches, S K should be one-fortieth of an inch.

* Compare D. Trowbridge, *Amer. Jour. Sci.*, II, xxxvii, 352-3; D. Kirkwood, *Amer. Jour. Sci.*, II, xxxix, 66-9; S. Alexander, *Proc. Amer. Assoc.*, Cincinnati, 1851 (oral discussion only).

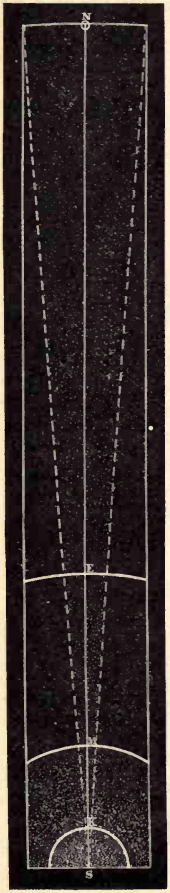

Fig. 36. — Illustrating Increase of Density toward the Centre of the Nebulous Spheroid.

Now let us imagine the sphere whose radius is S N rotating about an axis passing through S. The point K is that at which, if an opposing force equal to the energy of rotation should be applied, it would completely arrest the rotation (supposing the spheroid rigid), without producing any tendency of the end S, of the radius, to move out of its place. Now, considering that the point K is only one two hundred and thirty-fourth of the distance from S to N, we may easily imagine to what extent the mass of the matter must be gathered about the centre S.

What then may be inferred from such relations of density? It seems manifest that the exterior portions must contract much more rapidly than the interior. Their velocity would, therefore, tend to a more rapid acceleration. As the mass was not rigid, the exterior parts must have actually experienced a more rapid acceleration. Now, if an outer planet revolves with a greater velocity in reference to the next interior, the ratio of their periodic times is brought nearer to a ratio of equality than before; and this is in the direction toward the rate required by Kepler's third law; and we are per-

fectly at liberty to assume that the cause here considered is the one which brought the periodic times to the relation expressed by that law.*

But it may be further suggested, that if the central parts acquired most of their condensation *before* rotation began, they may be in a state of slower rotation than the more external parts. In this case, the friction of the rapidly accelerating exterior portions upon the interior portion, would prevent the accelerating tendency from being fully realized, and thus the planetary rings, and the planets themselves, would have a slower orbital motion than would be indicated by the volume of the shrinkage, and might fall into conformity with Kepler's third law. Finally, each process of annulation removed from the spheroid its most rapidly rotating portion, and left only a slower rotating remainder. The sun, which remains, may be conceived as having undergone many thousand times less contraction since rotation began, than the matter about the equator of the primitive spheroid.† It is the remnant of an original nuclear portion, and has acquired but little more than its ancient density. Much of the increase of density due to cooling has been nullified by relief

* Mr. D. Trowbridge expresses the opinion that "the angular velocity of the external parts would not be much increased except by friction," and would thus tend to rotate according to Kepler's third law (*Amer. Jour. Sci.*, II, xxxviii, 357). Since the internal parts have experienced more contraction than the external, it follows that their rotary velocity must have been increased more than that of the external, *if the condensation took place after rotation had begun*. In this case, Mr. Trowbridge's conclusion would be sound. But it seems very supposable that the generation of the rotation was a later event than the aggregation of the nebulous matter, and hence the condensation at the centre existed *before rotation began;* and the development of that central density has not, therefore, accelerated the central rotation.

† Ennis has conceived a more rapidly rotating exterior retarded by friction upon the interior as the explanation of the apparent discrepancy between theory and fact (J. Ennis, *Origin of the Stars*, chs. xvii, xix, and xxii). But he supposes the original rotation imparted only to the exterior by currents descending from higher to lower levels (p. 232), and supposes the interior to have acquired its rotation by friction with the exterior—though in some cases a general rotation may have been earlier generated by mutual collisions.

from the pressure of abandoned rings. In this view, the sun's present rotary velocity might be nearly that which had been acquired at a very early period. It should, therefore, be vastly less than the rate required by the simple laws of contraction.

Similar reasoning in reference to the periods of Jupiter's satellites shows them to have been similarly retarded; but the retardation is only about one-fifth as much as in the case of the planets. This is what we should expect according to the nebular theory, since the mass of Jupiter is much less than that of the sun, and the difference in density between the central and exterior portions would be less.

From these two general courses of reasoning, it seems legitimate to conclude that the ratios of the periodic times of the planets resulting from an annulating nebula which began its rotation after condensation about the centre, must approach nearer a ratio of equality than they would if, as is generally assumed, the rotation of the nebula began before central condensation from gravity had been effected, and the velocities of rotation had been determined by the whole contraction. This diminished ratio of periodic times may result from an increased relative acceleration of external parts, or from a diminished acceleration of internal parts in acting on the external.

Should it seem improbable that rotation began after condensation had taken place, it may readily be admitted that in the case of our solar nebula, and accordingly in other cases, an exceedingly slow rotation existed before full condensation. In many cases the initial rotation would probably be extremely slow, both because generally the accessions of new matter would be relatively so small that their impact would possess little efficiency, and because, striking, with equal probability, on all sides of the centre, their effects would tend to neutralize each other. It will be borne in mind also, that in aggregations as inco-

herent as nebulæ, collisions would develop vastly less rotary effects than collisions between solid bodies.

3. *The Periodic Times of the planets are shorter than the Nebular Theory allows.**—It is claimed that the principle of conservation of areas would give the spheroid at the orbit of Mercury a period of rotation equal to about eighteen hundred of Mercury's years; so that Mercury when detached from the sun must have had about eighteen hundred times smaller a quantity of motion than at present. This result is reached by taking the sun's actual rotation period as a starting point, and calculating from what Mercurial velocity it must have resulted on the principle of equal areas.† But this mode of calculation is wholly fallacious, since we have abundant reason for believing, as already explained, that the sun's actual rotation has not resulted simply in accordance with the law of equal areas in a contracting homogeneous medium. Investigators of this subject generally admit that the sun's acceleration of rotation has been diminished. Moreover, the great central condensation of the primitive nebula prevented contraction and acceleration in the same ratio as was experienced by the remoter and more tenuous zones. The result of the comparison between Mercury's actual velocity and that which he must have had on the principle of equal areas, calculating back from the sun, is precisely what the progress of the nebular evolution would require;

* Rev. S. Parsons, *Meth. Quar. Rev.*, Jan., 1877, p. 151.

† Let R = radius of sun; r = radius of nebula when expanded to Mercury's orbit; θ' = angular velocity of the sun, and θ = angular velocity when expanded to Mercury's orbit. Then by the principle of equal areas,

$$\theta : \theta' :: R^2 : r^2; \ \therefore \theta = \theta' \frac{R^2}{r^2}. \quad \text{Also } \theta' = \theta \frac{r^2}{R^2}.$$

But $\theta' = 0°.59$ per hour; $R = 430{,}000$ miles; $r = 35{,}750{,}000$ miles; therefore, $\theta = 0°.00008536$ per hour. But Mercury's actual angular velocity is $\frac{360°}{87.97 \times 24} = 0°.1705$ per hour. Hence his actual angular velocity is $\frac{.1705}{.00008536} = 1998$ times as rapid as it should be on the principle of equal areas.

and tends to confirm the nebular theory instead of weakening it.

It would be quite as legitimate to assume Mercury's period as a starting point and inquire what must have been the sun's angular velocity. This would show that the sun's velocity is 1998 times too slow. But this underrate of the sun's rotation is quite in accordance with our reasoning.

This objection is substantially the same as the last. In that it is maintained that the orbital velocity of each planet is too slow in relation to planets exterior to it. Here it is maintained that a planet's orbital velocity is too rapid in reference to a planet interior to it. The two propositions are convertible.

4. *The Periodic Time of Phobos, the inner satellite of Mars, is too short.*—M. Faye, in the first of his important memoirs on nebular cosmogony,* has presented it as a difficulty in the theory of Laplace that the inner satellite of Mars revolves in about one-third the period of the planet's rotation on its axis. "The period of rotation of a planet, said Laplace, must be, according to my hypothesis, less than the period of revolution of the nearest body which circulates around it. * * * Nor is this the sole exception to the theorem of Laplace. The same is true of a part of the rings of Saturn, as was observed some time since by M. Roche. There must exist, therefore, some defect in the mother idea of the theory."

Undoubtedly the Laplacean conception of nebular cosmogony must be somewhat modified. Many facts brought to light within the last three-quarters of a century are now

* M. Faye, *Comptes Rendus*, tom. xc, 569, March 15, 1880. Prof. C. A. Young also, in a lecture delivered in New York in January, 1883, speaking of the theory of Laplace, is reported to have said, "Whether this system can be true in its entirety I very much doubt. It is necessary to suppose some change in its mode of action; for otherwise the moons of Mars never could revolve quicker than the rotation of the planet itself. Yet something like this may be the correct theory."

available as a basis for reasoning, and it is necessary to modify some of the details of his theory. Laplace reasoned on the assumption of an absolute void in the interplanetary spaces, and he obtained only a first glimpse of the influence of tides upon the rotation-period of a planet or satellite. We now understand that the spaces around us are thickly occupied by particles of matter which I have designated "cosmical dust." We believe generally, in the existence of a material "ether." The mathematical theory of tidal action has very recently been followed out in its remote consequences to such an extent as to unfold new and surprising cosmical effects in the primitive and ultimate stages of planetary life.

I have already pointed out the necessary influence of the storm of meteoroids in transforming the energy of orbital motion in any planetary body, but especially in bodies as small as the Martial satellites. It is entirely credible that the satellites of Mars, and especially the inner and smaller satellite, should by such means, have been drawn nearer the centre of their motions, and thus accelerated in orbital velocity. When Phobos was 12,480 miles distant from the centre of Mars, its period of revolution was three times its present period. It then very nearly equalled the day of Mars, and was just two-thirds the period of the outer satellite, Deimos.*

But it is manifest that an ulterior result of solar tidal action upon any planet whose rotation has become synchronous with that of its dominant satellite (whether by acceleration of the satellite or retardation of the planet)

*The relation between distances and times is given by Kepler's third law from which

$$t : t' :: r^{\frac{3}{2}} : r'^{\frac{3}{2}} \text{ and } t' = t\left(\frac{r'}{r}\right)^{\frac{3}{2}}.$$

To find at what distance a satellite will perform its revolution in a period n times as great, we have $t' = nt = t\left(\frac{r'}{r}\right)^{\frac{3}{2}}$. From this $r' = n^{\frac{2}{3}}r$, and in the case of Phobos,

$$r' = 3^{\frac{2}{3}} \times 6{,}000 = 12{,}480.$$

will be a further retardation of the planetary rotation, so that the day will become longer than the lunar month, as in the case of Mars and Phobos. It is at least conceivable, on physical principles, that the relation of the motions of these two bodies is an incident of the old age of the Martial system.

5. *We have no adequate cause assigned for the inauguration of a Rotary Motion.*†—I believe the considerations heretofore presented (pp. 94–106) must convince any unbiased mind that the chances of the causation of rotary motion are nearly as infinity to unity. It may be well, however, to correct a misapprehension which has been used against the theorem that attraction from without would inaugurate rotation. Mr. Parsons says, in effect, that such attraction would, indeed, initiate rotation about the shortest axis; but the prolateness caused would be directed constantly toward the attracting body, and would, like a great tide, promptly arrest the rotation which had been begun. But, as all nebulæ must experience a motion of translation, this attracting body unless moving in the line of the prolate axis, would finally deflect this axis, and as the body should pass to such distance that the comparative influence should be null, the prolate nebula would cease to be prolate, and would be left in the process of a slow rotation. Or if, while the attracting body remains in the neighborhood, a third body should pass through such a position as to influence one extremity of the prolate axis more than the other, this influence might be sufficient to overcome the fixity caused by the first attracting body. But, it will be recalled by the reader that the most plausible conception of the forming process of nebulæ represents them as falling together and acquiring of necessity a rotary motion from an early stage of their existence.

† Rev. S. Parsons, *Methodist Quarterly Review*, January, 1877, 144-5; Rev. W. B. Slaughter: *The Modern Genesis*, ch. iii.

§ 3. OBJECTIONS BASED ON RELATIONS OF PLANETARY POSITIONS.

1. *The inclinations of the planetary orbits to the plane of the sun's equator.**—It is sometimes pretended that all the primary and secondary orbits should be strictly coincident; and it is at once evident that by the theory, they must have been so, *if the system had assumed form in the absence of all perturbating influences from without.* This is the unconditional and unwarranted assumption of the objectors. But we know, in the first place, that perturbating influences could not have been absent. The grave misapprehension exists in some minds that the nebular theory assumes a complete evolution through the action of its own internal forces alone. Rev. W. B. Slaughter employs the following language: "We must not forget that this cosmical sphere is revolving in a void. There is no external matter whose friction or attraction can modify the result. If it be alleged that there is other matter in the universe whose attraction must have reached the cosmical sphere and affected it, we reply that *the nebular hypothesis does not take such external attractions into account.*† It professes to find all its world-forming forces within the mass."‡ This is a profound and fatal misconception, but one which is made the basis of much of Mr. Slaughter's criticism. In fact the system of Neptune is so far removed that we may say it feels but slightly the controlling influence of the sun, while the stellar masses must exert an influence somewhat perceptible. A similar remark may be made in reference to Uranus and Saturn. Moreover when one planetary orbit should have been thrown out of coincidence with the plane of the solar

* Rev. W. B. Slaughter: *The Modern Genesis*, ch. vi.

† It is a sufficient reply to this to refer the reader to the nebular theories of Kant and Laplace presented in part IV, chap. ii and iv.

‡ *The Modern Genesis*, 68, 69.

equator, it would act on all the other planets to produce the same kind of disturbance. That the inclinations in question are affected by the mutual attractions of the planets is a well settled principle in cosmical physics; and nothing is more supposable than that the whole value of the inclinations has been created by these or kindred causes. Sir Isaac Newton says: "While comets move in very eccentric orbits in all manner of positions, blind fate could never make all the planets move in one and the same way in orbits concentric, some irregularities excepted which may have risen from the mutual actions of comets and planets upon each other, and which will be apt to increase till this system wants a reformation." * However, in spite of Newton's apprehension, we now know, from the progress of the recognized oscillations in these planes,† it is ascertainable that in the course of time they return nearly to the positions from which theory supposes them to have started. Thus it appears that Mercury will sometimes coincide with the plane of the sun's equator; Venus will approach within 5° 25′; the earth within 3°; Mars, within 10°; Jupiter, within 5°; Saturn, within 5° 5′; Uranus, within 5°, and Neptune within 5° 8′. Similarly, the plane of the moon's orbit will approach to within 18° of coincidence with the plane of the earth's orbit. The proper plane of reference, however, for these inclinations is not the ecliptic, which is only the position in which the ever-changing plane of the earth's orbit happens to lie at the present time, but the "invariable plane of the solar system." With this the planets make only the angles indicated thus: Mercury, 6° 20′ 58″; Venus, 2° 11′ 14″; Earth, 1° 35′ 19″; Mars, 1° 40′ 44″; Jupiter, 0° 20′; Saturn, 0° 55′ 31″; Uranus, 1° 1′ 45″; Neptune, 0° 43′ 25″. In the course of time these inclinations will reach

* Newton: *Optics*, p. 376.

† See Stockwell, *Smithsonian Contributions to Knowledge*, xviii.

the following minima: Mercury, 4° 44′ 27″; Venus, 0° 0′ 0″; Earth, 0° 0′ 0″; Mars, 0° 0′ 0″; Jupiter, 0° 20′; Saturn, 0° 47′ 16″; Uranus, 0° 54′ 25″; Neptune, 0° 33′ 43″.* Now it would seem that instead of any material conflict with the theory in this state of facts, we discover an impressive confirmation of it.

2. *The Breadth of Intervals between the planetary orbits is not clearly explained on the nebular theory.*†—It has been suggested that instead of a periodic disengagement of a ring of considerable mass, the equatorial periphery would continuously flatten out into a continuous disc-like expansion; so that nearly the whole nebulous mass would ultimately assume a discoid or flatly lenticular form, when annulation and planetation would take place in all the rings simultaneously. Under this view the rings should be more numerous, or at least more approximated to each other. I have given this subject considerable study, and have reached the conclusion that the original opinion of Laplace is the more probable one. I have attempted to show ‡ that the act of annulation would be periodic, and the reader is referred to the statements already made.§ The intervals between the planetary orbits, therefore, instead of conflicting with the nebular theory, ought to be cited as confirmation.

It might be said further, that the various inclinations of the planes of the planetary orbits is a circumstance less likely to result from a simultaneous origin of the planets than from successive origins.

3. *The nebular theory does not account for the Elliptic Forms of the planetary Orbits.*—The equatorial periphery

* J. N. Stockwell, *Smithsonian Contributions*, xviii, Doc. 232, pp. 166, 169.

† Newcomb: *Popular Astronomy*, 497-8. This is not presented by Professor Newcomb as a fatal difficulty, but is only alleged against a non-essential feature of the Laplacean hypothesis.

‡ Part I, Chap. ii, § 3, 3.

§ Hinrichs concludes that the process of annulation would be periodic, and that the intervals would be equal (*Amer. Jour. Sci.*, II, xxxix, 140 1, 144-7).

of the rotating nebula must have been at all times nearly circular. This would result in a circular ring and a circular orbit for the planet. Let us examine the point.

(1.) I have stated above (p. 160) that a reduction of the central mass S, Figure 35, would cause the planet to retreat. It is scarcely supposable that a motion away from S would be inaugurated without carrying the planet, by virtue of its inertia, beyond the point of equilibrium between centrifugal and centripetal forces. Brought to a halt at a point beyond this equilibrium, it would be in the position of a body let fall toward S, but actuated at the same time by a strong transverse impulse. I have already explained (p. 67) that under such circumstances the planet would describe an elliptic path around the centre of attraction.

It is not necessary to conceive the planet as retreating with the suddenness indicated by the dotted line A *c*. The result would be the same whatever number of revolutions it might make in reaching its remotest point.

If these views are correct, the amount of a planet's eccentricity, other things being equal, should be proportional to the mass of the planet next interior. Saturn, with the planet Jupiter next interior, should have a greater eccentricity than Uranus with the mass of Saturn next interior. Accordingly the eccentricity of Saturn is .056, while that of Uranus is .046. So the eccentricity of Mars should be greater than that of the earth. In fact the eccentricity of Mars is .093, while that of the earth is .017. So the eccentricity of the earth,.017, as determined by the withdrawal of Venus, is greater than that of Venus, .007, as determined by the withdrawal of the smaller planet Mercury. The eccentricity of Mercury is .206 with no interior planet certainly known to have caused it. Until a considerable interior mass is demonstrated, it is allowable to attribute this comparatively

large eccentricity to the proximity of Mercury to the perihelia of cometary and other erratic bodies drawn toward the sun. Most of the asteroids have large eccentricities; but these may be attributed chiefly to the influence of neighboring planets, especially of Jupiter. The small masses of Mercury and the asteroids would, of course, render them specially susceptible to perturbative influences.

(2.) The circular orbit is one of unstable equilibrium in the actual universe. It is impossible of conservation. Every external attraction to which the planet might be subjected would pull it from its path.

Suppose a planet revolving in a circular orbit, the perturbative influence of any attractive body, as, for instance, a neighboring planet, would draw it from a circular path; and as that influence should again diminish, the planet would swing toward its circular orbit again. But it would swing too far. By the laws of mechanics we know that its orbit would henceforth be elliptic. It is shown as the result of the most elaborate calculations, that the eccentricity of each planetary orbit is actually affected by the attraction of each sister planet; and the value of the eccentricity increases and diminishes according as the resultant perturbation increases or diminishes in amount. Beyond all question this cause must convert an original circular orbit into an elliptic one.

§ 4. OBJECTIONS BASED ON RELATIONS OF PLANETARY MASSES AND DENSITIES.

1. *The mass of the Asteroids is smaller than the nebular theory requires.*—All the asteroids known aggregate less than $\frac{1}{4000}$ the bulk of the earth, and their mass probably is much less in proportion. Leverrier calculated that the greatest possible mass of all the asteroids, discovered and undiscovered, could not exceed one-fourth of the earth's

mass. Such an asteroidal mass would explain the secular motion of the perihelion of Mars. But a revised determination of the earth's mass shows that the earth's influence is almost sufficient to account for this secular motion; and hence the total asteroidal mass must be exceedingly small. But I am not aware that the nebular theory necessitates any direct simple relation between the masses of the planets in a system, though it is true that the mass of each planet is connected with its period of revolution and mean distance from the body around which it revolves. It is also true that in general we should expect the remoter planets to possess larger masses because formed from rings having larger circumferences. This is generally the case, and is so far a confirmatory circumstance. But the theory carried out in the midst of space already populated by numberless moving bodies does not forbid the disengagement of rings of small mass. The asteroidal and the Martial masses may both have been originally less than the principle of regular gradation permits. But it may also be suggested that both these masses may have been reduced from their original amounts by precipitation of portions into the solar nebula before the latter had shrunken sufficiently within the perihelion positions of these masses.*

2. *The Disrupted State of the asteroidal mass is an Anomaly in the operation of the theory.*—The circumstance is extraordinary, but not anomalous. The Saturnian rings are extraordinary, but so far from anomalous that they bring strong testimony to the soundness of the theory.

(1.) I have heretofore (p. 119) suggested the probability of the stratification of the nebulous rings. This suggestion seems to have occurred to Laplace. Now, with the disruption of a stratified ring, it is quite conceivable that numerous planets might result, while it is equally con-

* As suggested by D. Kirkwood, *Amer. Jour. Sci.*, III, i, 71.

ceivable that they might coalesce into one. Either contingency is entirely within the provisions of the theory.

(2.) Moreover, it was a suggestion of the late Professor Benjamin Peirce that an intra-Jovian ring might have persisted until excess of perturbation and consequent oscillation "brought it into contact with the planet Mars, by which collision it was broken into asteroids.*

(3.) Finally, Professor Clerk-Maxwell in investigating the conditions of equilibrium of Saturn's rings,† reached the conclusion that undulations in a fluid ring, under certain circumstances, would result in breaking up the ring into small satellites. Mr. Trowbridge has applied this conclusion to a ring persisting between Mars and Jupiter until it had attained the condition of an incompressible fluid, when it would, at a later period, be broken into a multitude of asteroids.

The possibilities of the nebular theory therefore deprive of all force any objection based on the existence of a group of asteroids.‡

3. *The densities of the outer planets are so low that if composed of the same materials as the earth they should be of a temperature sufficiently high to be self-luminous.*§ —All recent observations lead toward the opinion that these planets are enveloped in a thick mantle of aqueous vapors. It is only the exterior of this envelope which is exposed to our view. On planets of such mass, the density and

* B. Peirce, *Gould's Astronomical Journal*, ii, 18; also *Annual of Scientific Discovery*, 1852, 379. Compare G. Hinrichs, *Amer. Jour. Sci.*, II, xxxix, 54.

† Clerk-Maxwell: *On the Stability of the Motions of Saturn's Rings*, 1856.

‡ Mr. Herbert Spencer adheres to Olber's theory of an exploded planet, and sets forth the grotesque conception of a planet liquefying and even solidifying around a gaseous nucleus, the tension of which finally overcomes the strength of the shell (Spencer, *Westminster Review*, lxx, 123, July, 1858; *Essays, Scientific, Political and Speculative*, second series, New York, 1864). Other suggestions in this essay must be regarded as entirely an evolution from inner consciousness, among which that of hoop-shaped rings is sufficiently extraordinary and gratuitous.

§ Rev. W. B. Slaughter: *The Modern Genesis*, ch. xiii.

perhaps the vapor-bearing height of the atmosphere must be many times greater than on the earth. By all this amount then, the diameter of the aqueous envelope exceeds that of the planetary body. Our exaggerated estimate of the diameter of the planet results in an underestimate of its density. After making all corrections, and admitting that Jupiter is still in a heated condition, it does not appear that the densities of the outer planets are at all different from what the nebular theory requires; since that demands progressive increase in density toward the centre. (But see Chap. iii, §§ 5 and 6, and Chap. iv, § 5.)

A fundamental fallacy, which develops itself in many other forms, is the assumption that the nebulous spheroid proceeded to increase in density precisely in proportion to its diminution in volume, and that the rate of contraction must be exactly in the inverse ratio of the mass. The contraction is proportioned to the loss of heat *in the whole mass.* The power of radiation is proportioned to the surface; and the loss of heat is in the same proportion, *provided the temperature of the whole mass diminishes equally.* But the surface is proportional to the square of the radius, while the mass, when the density is uniform, is proportional to the cube of the radius. In other words, the surface diminishes more slowly than the mass; so that the rate of radiation diminishes less rapidly than the mass even when the whole mass cools uniformly. But no large mass can cool with complete uniformity; and in a mass which has become solid on the exterior or throughout, so as to prevent convection of heat by free mobility of the particles, the rate of cooling will be also retarded by the process of conduction from the interior to the surface. Hence every planetary mass must proceed at a continually retarded rate of cooling.

For these reasons no two planets of the same mass can have attained to temperatures proportioned to their ages.

The temperature is a function of the age, but not a simple function of it. Nor can two planets of the same age but of different masses have attained to thermal conditions proportional to the masses. Nor, if the thermal conditions were the same, would their densities be the same. Density depends on thermal conditions and on mass. Hence all the captious criticisms on the nebular theory based on supposed non-conformities of the planetary densities are founded on misapprehension of the physical conditions involved.

§ 5. OBJECTION BASED ON RELATION TO TERRESTRIAL DURATION.

*The nebular theory does not admit as great an Age for the World as geology requires.**—Sir William Thomson, on the basis of the observed principles of cooling, concludes that not more than ten million years can have elapsed since the temperature of the earth was sufficiently reduced to sustain vegetable life;† and on the duration of tidal action reaches a similar result.‡ Helmholtz calculates that twenty million years would suffice for the original nebula to condense to the present dimensions of the sun. Professor S. Newcomb requires only ten million years to attain a temperature of 212° Fahr.§ Croll estimates seventy million years ‖ for the diffusion of the heat which would be produced by the collision of two such nebulæ as would constitute the primitive nebula postulated by the theory. But meantime Bischof calculates that 350 million years would be required for the earth to cool from a temperature

* Rev. S. Parsons, *Meth. Quar. Rev.*, Jan., 1877, pp. 142-3.

† Thomson and Tait: *Natural Philosophy*, Appendix D, also §§ 832. 833, 834, 847, 848 (but 847–9 cancelled in Glasgow address); *Trans. Roy. Soc. Edinb.*, xxiii, pt. I, 157, 1862.

‡ Thomson, *Trans. Geol. Soc.*, Glasgow, iii, 1.

§ Newcomb: *Popular Astronomy*, 509.

‖ Croll: *Climate and Time*, 335.

of 2,000° to 200° centigrade. Reade, basing his estimate on observed rates of denudation, demands 500 million years since sedimentation began in Europe.* Lyell ventured a rough guess of 240 million years; Darwin thought 300 million years demanded by the organic transformations which his theory contemplates; and Huxley is disposed to demand a thousand millions. "Here," says Mr. Parsons, "is a clear conflict between the naturalist and philosopher. Either the geologist must be compelled to surrender some hundreds of millions of time, or the physicist must give up the nebular theory as the foundation of the condensation hypothesis of the sun's heat and the earth's present temperature. The geologist will probably carry the day, and the nebular hypothesis will have to give way to some other speculation relative to the origin of the solar system."

A better considered view of this diversity of estimates seems to me to be the following: Some biologists, impressed by the slowness of organic transformations, seem to close their eyes tight and leap at one bound into the abyss of millions of years, of which they have no more adequate estimate than of infinity. They have a sort of impression that some hundreds of millions would not be too much. They are destitute of the first exact chronological datum from which to set out. Similarly, certain physical geologists having roughly estimated the rate at which erosion is going on, make this best attainable knowledge the basis of a provisional calculation of the time required for all the erosion which they suppose to have taken place. Manifestly, the result involves too many guesses and estimates and best judgments to be of any value in subverting the significance of the uniformities of the solar system and the starry heavens. Lastly, the physicists have proceeded from more exact data, and by more exact methods, to results embracing fewer unascer-

*Reade, *Address Liverpool Geol. Soc.*, 1876.

tained elements and fewer assumptions than in either of the other cases. The shorter periods are, therefore, far most likely to represent the truth; and these are derived according to the principles of the nebular theory.

I shall hereafter show that physical science places the geologist in possession of facts which enable him, without receding from his best methods of calculation, to deduce a value for the age of the world, which lies quite within the limits fixed by physical investigation. The great fact to which I allude is the enormous exaggeration of the forces of sedimentation in the world's early history, due to the enormous development of tidal action at a time when the lunar mass was much nearer the earth than at present.

The conflict, therefore, between the physicists and the geologists is entirely imaginary. Even if it were real, it would be no more than a conflict between vague opinion and the results of calculations which themselves embody many data which are merely assumed.

§ 6. OBJECTIONS BASED ON RELATIONS OF COMETS, STARS AND NEBULÆ.

1. *Cometary phenomena ought to be provided for under the nebular theory, but this is impossible.**—This

*Rev. S. Parsons, *Methodist Quarterly Review*, January, 1877, pp. 132-4. Compare the views of D. Kirkwood, *American Journal of Science*, II, xxxviii, 16-18, who thinks a majority of the periodic comets have originated in the system, and says Faye's comet "may be regarded as a connecting link between planets and comets." Mr. Herbert Spencer, also, has undertaken to show that many more comets approach our sun from the direction of the poles of the ecliptic than from the direction of its plane; and hence indicate a physical connection with our system (*Westminster Review*, lxx, 110-12, July, 1858). He thinks comets to be mere detached flocculi left behind during the contraction of the solar nebula. Much information in reference to comets and their connection with meteoric matter has been gained since Mr. Spencer wrote, and his suggestion does not seem as plausible as it did. Moreover, if comets have chiefly originated within the sphere of attraction of our system, it is improbable that so many of them should have acquired hyperbolic orbits which carry them indefinitely beyond the controlling influence of our sun. Nor does it seem credible that after time enough has elapsed to form and consolidate so many planets, those cometary

pretence is totally inadmissible. Only two reasons have been presented on which it can be based: (1.) Some of the comets have eccentricities but little greater than those of a few of the asteroids, and thus a gradation exists from the planetary orbit nearly circular to the cometary orbit with extreme eccentricity. (2.) That a physical connection actually exists between the comets and planets is shown by the coincidences between the aphelia of groups of comets and the mean distances of certain planets, especially the four outer ones.

Now, the objections to this claim, in addition to the suggestions thrown into a note, are the following:

(1.) Neither Laplace nor any subsequent astronomer has been impressed by any such relations between the comets and planets as to suggest that they belong to the same system, or have had a common history. Laplace says: "In our hypothesis the comets are strangers to the planetary system. In regarding them, as we have done, as small nebulæ wandering from solar system to solar system, and formed by the condensation of nebulous matter spread with such profusion through the universe, it is apparent that when they arrive in that part of space where the attraction of the sun is predominant, he forces them to describe elliptic or hyperbolic orbits. But their movements

flocculi should be just arriving; nor, if just arriving, should they be seen moving with velocities which would carry them across the diameter of our system in a few years and across the sphere of our sun's attraction in a few centuries. As to Mr. Spencer's first assumption, the facts of the case have been collated by Lamont, and stand as follows: Of comets having an inclination to the ecliptic ranging from 0° to 30°, 24 have direct motion and 15 retrograde. Of those from 30° to 60°, 34 have direct motion and 42 retrograde. Of those from 60° to 90°, 27 have direct and 29 retrograde motion. Thus, their inclinations are somewhat *equally distributed* from the equator to the pole. At the same time, we notice the concurrent fact that eighty-five of these comets have direct motion and 86 retrograde.—Lamont: *Astronomie und Erdmagnetismus*, Stuttgart, 41.

M. Faye also records the opinion that the comets belong to our system, and in the modified nebular theory which he has advanced, attempts to show how their eccentric movements might have originated (*Comptes Rendus*, tome xc, pp. 640–2).

being equally possible in all directions, they should move indifferently in all directions, and with all inclinations to the ecliptic, a demand which conforms to what we observe. Thus the condensation of nebulous matter by which we proceed to explain the movements of rotation and revolution of the planets and satellites in the same direction, and in nearly the same plane, explains equally why the movements of the comets depart from this general law." *

(2.) It signifies nothing if, out of hundreds of comets which have been recorded, we are able to select a few with small eccentricity. The very theory which we maintain in reference to the origin of the comets requires that some of them should have direct motion and a minimum of cometary eccentricity. But it also implies that among the whole number of comets, retrograde motion should be nearly as common as direct motion, and that many of the cometary orbits should be ellipses of extreme eccentricity, or even parabolic or hyperbolic — all according to actual observation. The objector is not at liberty to employ certain exceptional characteristics of a group of phenomena in determining upon a classification; he is bound to take account of the entire assemblage of characters. This principle of reasoning is so elementary that one can hardly account for its disregard except through a spirit of captious criticism.

(3.) A physical connection certainly exists between the comets and the planets, and the two classes could not coexist in the presence of each other without manifesting it; but this does not imply that such interaction has always existed, or that the two classes of bodies have had a common history. Introduce any other strange body into the system, and the same kind of physical connection would be immediately established. It is generally understood that a cometary body entering the system is very

* Laplace: *Système du Monde*, ed. 1824, p. 414.

likely to be so attracted by some one of the planets that a new career and a new pathway must date from the time and place of such disturbance. A comet starting on a new career from the orbit of Jupiter might thenceforward move in an elliptic orbit having its aphelion at about the distance of Jupiter from the sun.

2. *The requisite Tenuity of the assumed nebula in filling the orbit of Neptune would result in its Dissipation into infinite space.**—Since, under standard conditions of pressure and temperature at the earth's surface, the molecules of hydrogen have a motion among themselves of an average velocity of 6,000 feet per second, and those of oxygen 1,800 feet, and those of air 1,400 feet per second, these velocities would be so increased in the supposed nebula that the molecules would fly off into space. It is calculated that at a freezing temperature the motion of hydrogen atoms would be 9,000 feet per second, while a velocity of 520 feet per second would be sufficient to overcome the restraining force of gravity. Still more would this be the case if the nebula were intensely heated.

I do not conceive it necessary to discuss the merits of a speculation, one of the consequences of which is to negate the existence of something which stands revealed to the ocular sense. The speculation concludes that a nebula sufficiently tenuous could not exist, and here it is existing before our eyes. What are those faint films described by Sir William Herschel as barely discernible in his great telescope and spreading over several square degrees of space?† What is the nature of the zodiacal light? What is the tenuity of the tails or even the comæ of comets, through thousands of miles of which faint starlight is able to pierce, and which are so unsubstantial that the entire cometary collection—nucleus, coma

* Rev. S. Parsons, *Meth. Quar. Rev.*, Jan., 1877, pp. 141-2.

† Herschel, *On nebulous stars, property so-called*, Phil. Trans., 1791.

and tail—is unable to disturb perceptibly the movements of bodies as small as Jupiter's satellites? If these are not examples of matter sufficiently tenuous, which, notwithstanding their tenuity, are held together by the attraction of their parts, we should inquire what adequate warrant exists for the assumption that material molecules possess the power of continuous motion in one direction rather than a vibrating motion. And whether their motion is not instituted and limited by the immediate neighborhood of other molecules. And whether it is not conceivable that molecular attraction would restrain neighboring molecules from flying off an indefinite distance. And whether, finally, the objector has ascertained what degree of tenuity would so separate molecules or atoms that each in its motion should fail to strike another atom or molecule and be turned back by it.

But another point is overlooked by the objector. When it is calculated that the matter of the solar system uniformly distributed through a sphere having a diameter equal to Neptune's orbit, would possess a certain extreme degree of tenuity, this is merely a calculation. It may serve to give us a conception of the vastness of the space, but does not teach us anything respecting the actual tenuity or condition of nebulous matter. The tail of a comet is not a continuous gas. The matter of the zodiacal light is composed of discrete, solid particles. The nebulous rings of Saturn are not a continuous gas. Our conception of the crude condition of nebular matter views it as a cloud of floating masses and particles more or less dissociated, but tending slowly toward aggregation. Tens and hundreds of miles may intervene in some places. Each has its own motion in addition to the general motion of the cloud; and hence collisions frequently occur. If any aëriform matters exist, or are brought into existence, they are gathered chiefly about the masses and

particles. In a more advanced stage the collisions have become sharper, and the products and effects of collisions more conspicuous. Permanent luminosity begins to be maintained in the interior of the cloud, and gaseous media become more abundant. But I do not conceive the necessity of assuming that all the intervening spaces are filled with any form of matter; since the attractions of the solid or liquid parts might limit the action of an expansive tendency, as has been generally conceived in reference to the atmospheres of the planets. Meantime the heavier parts gradually settle nearer the centre of the nebulous cloud. Other nebulous clouds are precipitated upon this. Higher temperature, more general luminosity and more active rotation result. While the progress of aggregation continues, the evolution of a planetary system begins. Even at this stage we are not bound to assume that absolute continuity of substance extends through the nebula. (But see Part I, ch. i, § 7.)

3. *It is not physically probable that a ring would ever be detached.**—As acceleration should increase the equatorial protuberance, the transfer of particles from higher latitudes, and possessing slower motion, would act as a brake, arresting the excessive velocity, and thus forever preventing an excess of centrifugal momentum.

(1.) *Reason and observation affirm the probability of a ring.*—Laplace, who looked as profoundly as any one into the physical principles involved, was of a different opinion. And so have been nearly all writers on the subject. If contraction of total volume takes place, the sum of the radii vectores of the particles must be diminished, and then, if the principle of conservation of areas is not fallacious, the velocity of rotation *must* be increased. (See p. 106.) The increase *must* sooner or later exceed the limit

* Rev. S. Parsons, *Methodist Quarterly Review*, January, 1877; Rev. W. B. Slaughter: *The Modern Genesis*, ch. iv—a mechanically absurd objection.

of equilibrium between centripetal and centrifugal tendencies, to whatever extent progress toward that limit may be retarded by the transfer of particles from higher latitudes toward the equator. The denial of the conclusion is met by the rings of Saturn and the annular nebulæ, by the rings of Plateau, and even by the projection of water from a rapidly revolving grindstone.

(2.) *M. Faye's objection considered.*—M. Faye has also raised the objection that under such conception of the constitution of the primordial mass as was entertained by Laplace, annulation would never occur.* The idea of Laplace was, as M. Faye states it † "that the sun is, except as to incandescence, a globe similar to our own, solid or liquid, surrounded by an atmosphere. This atmosphere, enriched without doubt by certain materials more volatile than the others, was formerly expanded through the influence of original heat, as far as the orbit of the remotest planet, the velocity of rotation of the central globe being propagated through the successive layers by means of their mutual friction, in such a manner as to bring into perfect agreement the rotation of the atmosphere and that of the central globe. Through the influence of cooling the central globe contracted by degrees; its velocity of rotation, and consequently that of the atmosphere, underwent progressive acceleration. But there is a limit which the acceleration of the atmosphere could not surpass; it is that where the equatorial centrifugal force was equal to gravity; all outside of this ceases to belong to the atmosphere, and ought to begin a planetary revolution about the sun. But here, one thing, it seems to me, is forgotten. If the central globe contracts by degrees, through cooling, so should the atmosphere. But nothing proves that it will not contract so much as not to attain the limit just stated. It

* M. Faye, *Comptes Rendus*, tom. xc, p. 571.
† Compare Part IV, ch. iv, of the present work.

would suffice that to an augmentation of one thousandth in the velocity of rotation of the central globe should correspond a contraction of one and a half thousandths in the radius of the atmosphere, to cause that the latter should never part with any portion, and thus should never give place to the formation of a planet.*

"Modern studies have caused us to reject this conception. For us, the mass of the sun is in a state of fluidity more or less complete in all its extent. There exists no solid or liquid surface which marks the commencement of an atmosphere. That which we call the photosphere is only the region where the progressive lowering of the internal temperature permits certain vapors temporarily to condense and form a shifting zone of incandescent clouds. If, then, in former times, the sun possessed a greater volume, its entire mass must have been expanded, and the entire mass must have undergone contraction through the influence of refrigeration."

* If r and r' represent the equatorial radius of the "atmosphere" at two consecutive epochs, and have such values that $r' = r - \frac{r}{n}$; and if θ and θ' represent the angular velocities of the "central body" (and by hypothesis, also of the atmosphere) at the same two epochs, and have such values that $\theta' = \theta + \frac{\theta}{m}$; then the value of the centrifugal tendency on the equator of the atmosphere at the two epochs will be $r\theta^2$ and $r'\theta'^2$, and the condition of no augmentation of this tendency is expressed by equating these two values. Substituting the equivalents of r' and θ', the equation becomes

$$r\theta^2 = \left(r - \frac{r}{n}\right)\left(\theta + \frac{\theta}{m}\right)^2$$

whence $$m = \pm \sqrt{n(n-1)} + n - 1.$$

If m, the denominator of the fractional increase of the angular velocity, be taken at 1,000, then $n = 500$ very nearly. That is, if the angular velocity of the central body is increased $\frac{1}{1000}$, a corresponding decrease of $\frac{2}{1000}$ in the radius of the atmosphere would preserve the centrifugal tendency unchanged, and no part of the atmosphere would be abandoned. This result, it will be noticed, assumes that all the motion of the atmosphere is imparted by the rotation of the central body, and that the contraction of the atmosphere (which under the conception stated would be much more than that of the central *liquid* or *solid* central body) contributes nothing to the increase of its velocity. While M. Faye's reasoning is correct, it is extremely doubtful whether his premises express correctly the conception of Laplace.

So far M. Faye's objection rests only against an alleged particular conception of Laplace. It is true that Laplace employs language which might justify such an interpretation of his ideas as is set forth by M. Faye. That, however, is of little consequence, since those who hold to a nebular evolution of planets are not limited to methods of detail which seemed satisfactory to astronomers of the last century. Annulation under the Laplacean conception may be impossible, and yet both possible and probable under the modern conception of the solar constitution, and of the primordial nebular condition of the matter of our system.

But M. Faye next proceeds to show by mathematical reasoning that a sun constituted according to the modern conception would never annulate by the simple process of equilibrated equatorial zones.* I am persuaded, however, that errors have crept into his investigation, which vitiate his conclusion. However presumptuous it may appear to criticise the work of a mathematician of such masterly skill, it is certainly the privilege of every one to compare his conclusions with facts, and to scrutinize the tenability of his assumptions. The facts of the actual world convince us of the possibility of annulation through augmentation of centrifugal tendency. The orbital velocities of the planets are still such that centrifugal and centripetal

* The general formula which he employs to express the density of the nebular mass at any point whatever is

$$D\left[1-(1-\alpha)\sqrt[n]{\frac{r}{R}}\right]$$

where D represents the central density, R the radius of the solar [nebular] equator, r the distance from any point whatever to the centre, n an arbitrary positive number, and α a very small fraction. This gives a very feeble final density [that is, when r becomes equal to R], and at the same time a decrease of density as rapid as may be desired, from the centre to the surface, since n may vary from zero to infinity, and α may be replaced by zero,—a supposition which makes the surface density zero. This law, M. Faye remarks, is analogous to that which M. Roche (*Essai sur l'origine du système solaire*, 1873) has employed with full success for the terrestrial globe, and to that of Legendre and Laplace.

tendencies are equalized; and simple calculation shows that a heated nebulous mass, under certain conditions of internal density, beginning contraction with an initial rotation however slow, will acquire increase of rotational velocity up to the point of annulation.* Moreover, M. Faye, in approaching his conclusion, assumes as one condition, that "we do not admit the planets formed at the expense of the sun," an assumption which conflicts not only with our own nebular theory, but also with that subsequently expounded by M. Faye himself.† He thus finds the moment of inertia constant in all the history of the sun's contraction. Again, in determining the numerical ratio of the centrifugal tendency to the central attraction, he obtains the value of certain quantities *from the present condition of the sun.* Among these is the rotational velocity of the sun. This, I have elsewhere maintained, is an erroneous assumption, since we discover valid reasons for concluding that the actual solar rotation is not fully and simply the result of that secular acceleration to which we ascribe the action of ring-making.

I conclude, therefore, that we have good physical grounds for maintaining that in a highly heated, nebulous rotating spheroid, increase of angular velocity would proceed to such a limit that annulation would begin.

* Let θ and θ' represent the angular velocities of the nebula at commencement of contraction and at an epoch when annulation is possible, and r and r' represent the equatorial radii of the nebula at the same epochs. To find what amount of contraction is necessary to increase the primitive angular velocity θ to θ', we have

$$\theta : \theta' :: r'^2 : r^2,$$

whence

$$r' = \pm r \sqrt{\frac{\theta}{\theta'}}.$$

If $\theta=1$ and $\theta'=4$, $r'=\frac{1}{2}r$. Generally, if $\theta'=m\,\theta$. then $r'=r\sqrt{\frac{1}{m}}$. That is, the annulating radius varies, in different cases, inversely as the square root of the ratio of the primitive and annulating angular velocities, and is equal to the primitive radius multiplied by the reciprocal of the square root of that ratio. Now it is manifestly allowable to suppose such a law of variation of internal density that while θ increases to θ', r may decrease to r'.

† See § 8 of the present chapter.

The whole discussion may be supplemented by the suggestion that the initial rotary velocity of the nebula may be rapid. It arises, according to the views here set forth, from some primitive nebular collisions. Whatever rotary momentum may be thus imparted will be conserved during subsequent contraction; and increase of rotary velocity will proceed from this beginning. We are at liberty to assume any such initial velocity of rotation as would necessitate annulation at any subsequent stage.

4. *The want of uniformity in the composition of the fixed stars.*—Mr. Rutherford, in concluding a statement of results of the spectral examination of stars, says:* "We have long known that 'one star differeth from another star in glory'; we have now the strongest evidence that they also differ in constituent materials—some of them, perhaps, having no elements to be found in some other. What, then, becomes of that homogeneity of original diffuse matter which is almost a logical necessity of the nebular hypothesis?" To this it may be replied:

(1.) No such universal and absolute homogeneity is assumed. It is not admitted that even our solar nebula was completely homogeneous. If we discover identical substances in other orbs, that is a fact pointing toward an ancient material connection or common origin; but if we find evidence of some unknown substances, that is not sufficient to negate the significance of so many facts pointing to a common cosmical history; it is rather what ought to be expected where the different parts of the material system are separated by intervals so immense.

(2.) The indications from spectroscopic observations are yet too incomplete and too ambiguous to base any important negations on; but so far as stellar spectra have anything to testify, they tend wonderfully to *establish* the unity of substance throughout the visible universe.

*Rutherford, *Amer. Jour. Sci.*, II, xxxv, 77.

5. *The spectra of the nebulæ do not indicate sufficient pressure.**—It is in this assumed that the nebular theory implies that the various nebulæ should be in all stages of condensation; and hence, as different degrees of condensation give bright spectral lines of different breadths, some of the nebular spectra should afford broad lines. But as Mr. Plummer says: "From the observations of Huggins it would appear that the bright lines in the nebular spectra present no appreciable thickness in all those cases in which it has been possible to use a narrow slit. The lines have invariably been found to be exceedingly fine. Hence," continues Mr. Plummer, "we are furnished with distinct proof that the gases so examined are not only of nearly equal density, but that they exist in a very low state of tension. *This fact is fatal to the nebular theory.*" This is a most surprising example of inductive generalization. Only a few suggestions are required.

(1.) The nebular theory primarily and chiefly concerns the origin of the bodies of the solar system from a supposed primitive nebula. The phenomena of firmamental nebulæ have been summoned to illustrate and confirm the theory; but if it should be proved that such confirmation is wholly unattainable, the theory would still rest on all the analogies and physical relations which Laplace and many others have accepted as adequate ground of conviction.

(2.) It seems impossible that any unbiased judgment should hesitate to detect in the aspects of the nebulæ the evidence of the reality of their close relation to such a form and condition of matter as the nebular theory of planetary origin postulates. But the bright lines which they yield are not broad enough! Well, for all that, the bright lines declare that the nebulæ are *gaseous*, or at least contain

* Plummer, *Natural Science Review*, 1875; Rev. S. Parsons, *Meth. Quar. Rev.*, Jan. 1877, pp. 138-9.

gases, and that they are *self-luminous*, and their narrowness proclaims a high state of *rarefaction*. Here are three sentences of favoring testimony to oppose to one of unfavorable testimony. Let us see what that fourth sentence is worth. A nebula would not be a nebula unless it were tenuous and, in free space, so little condensed as to yield narrow lines. Has Mr. Plummer tried the effect of compressing a bit of nebula in a confined space, to see if its spectral lines would not widen? Next, the interior of the nebula is the region where tension must exist; but the light upon which Huggins experimented came necessarily from the exterior, where, by the laws of gaseous bodies, the tension must always be at a minimum.

(3.) If nothing more were to be said, the certainty of the inferences drawn from width of spectral lines is not yet sufficiently well established to outweigh the general evidences that the nebulæ are of such nature as has been commonly ascribed to them; still less to render nugatory the hundreds of indications manifested in the solar system that our planets and satellites have had a nebular origin. Neither, finally, can the assumed identification of elementary substances in the nebulæ be regarded as sufficiently certain to base on them any destructive criticism of the nebular theory. The correspondences of the spectral lines are not exact, and the inferences are merely provisional. The nebulæ may in fact exist in a state of elemental dissociation; and even our recognized elements may occur in the nebulæ in that state of ultimate decomposition into simple and universal world-stuff toward which our attention has been directed by so many modern investigators (see p. 48). In such case, the spectral lines would be produced under circumstances such as have not been created in our laboratories, and it would be impossible for us at present to give them a correct interpretation.

So far then, as nebular spectra testify at all, they indi-

cate a wonderful range of common conditions between the nebulæ and the sun, and tend, like stellar spectra, to *establish* the unity of substance throughout the visible universe, as also unity of fundamental conditions and unity of dynamical activities.

I think I have thus gathered together most of the objections offered in recent times,* to the theory of the nebular origin of the solar system. Very few of these have been offered by scientists who have looked intelligently into the physical relations of the assumed nebulous matter during the progressive cooling. The objections offered by this class relate only to matters of detail. The most numerous objections have been urged by those least competent to criticise, and by such have been paraded with greatest ostentation and most defiant dogmatism. Many of the objections admitted in the foregoing list are so truly frivolous that I have noticed them only to forestall the pretence that "numerous difficulties remain unremoved."

* An anonymous writer (*North American Review*, xcix, 1-33, July, 1864) has thrown aside the nebular theory as being only "a happy guess," and though conforming to observed phenomena as alleged, deriving more support from its character as a developmental hypothesis in harmony with the hypothesis of organic development, than from any sufficient ground for "the fundamental assumption of a nebulous matter." This writer recedes to the Aristotelian conception of "an infinite and endless variety of manifestations of causes and laws, without a discoverable tendency on the whole." It is quite astonishing that the recognition of order and unity in the method of the universe should be met, in some minds, by such a feeling of repugnance, while order, method and unity are the normal and necessary expressions of intelligence — of that Supreme Intelligence in whose defence they unconsciously stultify themselves. A finite intelligence does not exercise its high and characteristic attributes by a helter-skelter and immethodical production of results; but deems it first of all essential to fix upon a *plan* under which its whole range of action shall be adjusted and unified.

The account of the "nebular hypothesis" by Professor R. A. Proctor, in the last edition of the *American Cyclopædia*, unites the fundamental conception of Laplace with some of the fanciful suggestions of Spencer, and is completed with some of the characteristic features of the meteoric theory maintained by the anonymous writer last referred to. For an intelligent account of the nebular theory, see an article by Prof. John Le Conte in *Pop. Sci. Monthly*, April, 1873, 650-60.

The reader will notice that in many cases, several different admissible suggestions are offered to meet a single alleged difficulty.* This results from the fruitfulness of the physical conditions attending the nebular evolution. Many different modes of action for the production of a particular result are possible, and their conditional predication is, therefore, perfectly legitimate. It is not to be alleged that we are at a loss to assign physical explanations for the phenomena which we witness; or that our expedients are conflicting. Our inability to indicate specifically and categorically which of several possible modes of action has produced a given result, arises from the impossibility of knowing the value of certain factors in the problem, which would be conditioned by concomitant circumstances belonging to the history of the remote past. Especially must we always remain in ignorance of the amount, direction and epochs of perturbative influences exerted by masses of matter not involved in the transformations of our solar nebula. It is perfectly legitimate to assume that these have acted in such way as to produce the phenomena attributable to perturbations.

If, then, one or more rational explanations is offered for every assignable condition or phenomenon in our system, it is only an undiscerning judgment which can continue to allege a conflict between facts and the nebular theory; and in view of the large array of coincidences with the facts which no competing theory has ever attempted to explain, it would seem to argue a callousness to evidence to persist in denunciation of the fundamental conception as a physical explanation of the origin and history of our system.

* Still further explanations of difficulties are afforded by the theory of cosmic tides, and these will be indicated in connection with the exposition of tidal actions and reactions (Part II, ch. ii, § 6).

§ 7. WHAT THE NEBULAR THEORY DOES NOT IMPLY.

It is probably within the truth to say that much opposition to the theory has been aroused by a mistaken interpretation of its consequences. I desire, therefore, to state concisely what the truth of the nebular theory *does not* imply.

1. *It is not a theory of the evolution of the Universe.* — It is primarily a genetic explanation of the phenomena of the solar system; and accessorily a coördination in a common conception, of the principal phenomena in the stellar and nebular firmament, as far as human vision has been able to penetrate.

2. *It does not regard the Comets as involved in that particular evolution which has produced the Solar System;* — but it recognizes the comets as forms of cosmic existence coördinated with earlier stages of nebular evolution.

3. *It does not deny an antecedent history of the luminous fire-mist.* — It makes no claim to having reached an absolute beginning. The fire-mist may have previously existed in a cold, non-luminous and invisible condition. It may have emerged from the substance of the ethereal medium, or may have no consubstantial relation with it. The fire-mist and other nebulæ may consist of matter in a state of molecular division, or in aggregates of any mass. Other nebulæ may be intensely heated and in a state of chemical dissociation, or their luminous phenomena may arise from a condition of things unknown to terrestrial science. We only affirm that the primitive nebula from which our system was evolved possessed at a certain stage the physical properties of an intensely heated and highly tenuous vapor.

4. *It does not profess to discover the* ORIGIN *of things, but only a stadium in material history.* — Its starting point postulates *matter* and *energy*. It makes no affirma-

tion concerning the origin of these. It leaves the philosopher and the theologian as free as they ever were to seek the origin of the modes of being.* It glimpses matter in a certain phase of existence, having active forces within, impelling it along an intelligible and methodical career of development. It stands on the regularity of nature and writes a history revealed to the understanding. Matter and force are recognized as existing realities; but in reference to their subjective *nature* the theory is as silent as upon their origin.

5. *It does not deny the existence of* PLAN *and* PURPOSE *in the system of cosmic evolution.*—It insists that the plan is so fixed that the most confident calculations as to the future and past may be based upon it. It holds that the concomitant existences and the successive stages in the whole history are intelligibly adjusted to each other; and as it is a system of phenomena and events which human thought can grasp and contemplate, it is itself, philosophically considered, the expression of thought, and implies a Thinker possessing attributes as vast as the creation. Moreover, there is nothing in the scientific postulates or implications of the theory to contravene the affirmation that as the product of intelligence it must of necessity involve *purpose*; and as the force which existed in the beginning and is the moving principle through all the history cannot be conceived as active without a subject, nor as residing in an undiscerning, unthinking, involuntary subject, so the whole history of cosmical evolution is a display as wide as the universe and as enduring as time, of the ever-present activity of an Intelligent Personality controlling and effectuating all the operations of nature.

* "The problem of existence is not resolved. * * * The nebular hypothesis throws no light upon the origin of diffused matter. * * * The nebular hypothesis implies a First Cause * * * " — (H. Spencer, *Westminster Review*, lxx, 127, July, 1858.)

In the light of these statements, I desire to reproduce the opening paragraph of a review penned by a theologian whose profession, and whose creditable acquaintance with science should equally have restrained him from committing himself to a sentiment so divergent from the facts and so disparaging to the interests of religion. I leave the paragraph as food for reflection. It is as follows:

"Since the speculations of the evolutionists have been advanced with such boldness and plausibility, the nebular hypothesis has assumed an importance which it did not possess in the time of Herschel and Laplace. It is, in fact, the first link in the development theory by which it is attempted to bind together all nature in a rigid system of materialism, forever excluding the interposition of mind and the idea of a divine cosmos. Final cause is pronounced a chimera, and the first great cause is remanded to the sphere of the unknown."*

§ 8. PROPOSED MODIFIED FORMS OF NEBULAR THEORY.

1. *M. Faye's proposed modification.*—It is indispensable, in a general discussion of nebular cosmogony, to make adequate mention of some important modifications in the theory of world-genesis which have lately been offered by the distinguished Director of the Observatory at Paris. As these are applied by the author especially to the cosmogonic history of our system, rather than to nebular evolutions at large, the present is perhaps the most appropriate place for reproducing his views. I shall translate the greater part of his article in the "Comptes Rendus," *on the Origin of the Solar System.*†

"The hypothesis of Laplace is based on the preëxistence of a globe possessing all the mass of the solar system,

* Rev. S. Parsons, M.A., *The Nebular Hypothesis and Modern Genesis*, Methodist Quarterly Review, IV, xxix, 127, Jan. 1877.

† *Comptes Rendus*, xc, 637, March 22, 1880.

and all its mechanical energy under the form of rotation. Through the action of an intense heat whose origin is not explained, the atmosphere of this globe, for to him it was only an atmosphere, became expanded to the limits of the remotest planetary orbit of our system. In cooling, it abandoned from time to time, in the plane of the primitive equator, the materials of the planets. Under this new form, the primitive energy subsists unimpaired, but now wholly in the circulations which we find existing. Thus by the intervention of heat and the play of centrifugal force, Laplace caused to be produced a totally different distribution of the mass and of its movements. This corresponds, to a certain point, with what we see. But *this intervention of heat is itself a pure hypothesis.* To justify it, we must suppose with Poisson that there are in the universe, regions with very different temperatures, and that the primitive globe, by virtue of its motion of translation, had passed into one of the hottest.(1) *

"Observation leads us, meanwhile, toward other ideas. The nebulæ, where matter is disseminated over vast spaces, have always produced in us and other astronomers the conviction that they are the point of departure of evolutions very various, and resulting in ultimate formations the most diverse, such as simple suns, double, triple and quadruple suns, and globular masses of minute suns reckoned by thousands. It is necessary to contemplate the scene, on a fine evening, with the aid of a good telescope, under the guidance of an experienced astronomer who has had the goodness to select beforehand appropriate objects. The spectator finds himself then in the presence of a series of forms so varied — at first rudimentary, then more and more evolved — in the position of a naturalist passing through a forest, embracing in a glance of the

* Numerals in parenthesis refer to observations at the end of this Section. The foot-notes are by the present writer.

eye, the phases in the life of the same existence, although these phases demand in reality, for each tree, a long series of years Is it not natural to be inspired by these facts, so much the more as our own system appertains to the type the most common, and the easiest to comprehend, that of a nebulosity at first vague, then presenting a central condensation, being absorbed little by little, regularly, into a nebulous star, and finally into a single sun in the dark depth of the sky? Thus heat would no longer appear as an exterior agent which must be invoked arbitrarily. We see it develop itself by degrees at certain points of the nebulosity as a result of the energy proper to a vast dissemination of materials exerting a mutual attraction at a distance. This is then a natural phase in the series of phenomena. We might even conceive *an anterior state where the disseminated matter may have remained a long time dark and cold.* The marvellous indications of spectral analysis, and the mechanical theory of heat fully confirm this method of viewing the subject.

"Suppose, for the purpose of fixing these ideas, that the matter of our system had been thus disseminated in the beginning, in a spherical space having a radius a hundred times greater than that of the orbit of Neptune. Viewed at the distance of the planetary nebula whose parallax Dr. Brünnow has ventured to measure, this very year, at the Irish observatory at Dunsink, ours would appear with a diameter of only 5′. The density of the matter, supposing it continuous, would be two hundred and fifty thousand million [250,000,000,000] times less than that of a receiver with a vacuum of one thousandth.*

*I subjoin the following calculation:

Let d = mean density of matter of solar system, that of the earth being 1.
a = its volume, that of the earth being 1,
ρ = its density when expanded as described,
R = earth's radius,
r = radius of the supposed sphere.

Its temperature would be in the neighborhood of absolute zero, at an epoch when the stars now visible could not yet have been formed. In spite of this inconceivable tenuity, the attraction of the entire mass would be felt none the less in all its parts. Any molecule whatever circulating at the surface would have a velocity only ten times less than that of Neptune.* In the interior, the attraction of the entire mass goes on decreasing toward the centre *just in the ratio of the distance to that point*, and realizes

Then, since the density of the matter is inversely as its volume, we have

$$\rho : d :: a\tfrac{4}{3}\pi R^3 : \tfrac{4}{3}\pi r^3 :: a R^3 : r^3,$$

whence

$$\rho = \frac{R^3}{r^3} ad.$$

To find d, we may add together the masses of the principal bodies of the solar system (See *Annuaire du Bureau des Longitudes*, 1881, p. 135), giving 324,877.923, and also the volumes, giving 1,285,833.272 (this being the value of a), the earth being the unit of mass and volume; then dividing total mass by total volume, we get mean density in reference to the earth, .2526 (which is only .0004 less than the mean density of the sun alone). As the specific gravity of the earth is 5.66, and that of water in reference to air is 773.28 (*Annuaire*, p. 514,) we have

$$d = .2526 \times 5.66 \times 773.28 = 1106.79.$$

Also $r = 2{,}775{,}000{,}000 \times 100 = 2775 \times 10^6$, and R = 3959;

whence

$$\rho = \frac{(3959)^3 \times 1{,}285{,}833.272 \times 1106.79}{(2775)^3 \times 10^{24}}$$

$$= .0000000000004226.$$

This is the density of the matter compared with common air (which is 14.435 times the density of hydrogen). The density compared with air exhausted to one thousandth is .0000000000004226. Unity divided by this fraction gives 236,600,000,000, which expresses the density of air exhausted to one thousandth, compared with the density of the matter of the solar system when expanded to a sphere having 100 times the diameter of Neptune's orbit. The Sprengel air-pump exhausts to one millionth, and yet the air remaining in the receiver has 236,600,000 times the density of the matter of the solar system when expanded as supposed. Further, the matter beyond the sphere of Neptune, supposing the distribution uniform, would have been a million times the amount of matter within that sphere, which is 14,419,000,000 times less than M. Faye's supposition makes it. This shows an immensely greater tenuity of the extra-Neptunian matter, or, what is much more probable, a more limited extension of the matter. If the matter extended only as far as Neptune's orbit, its density was a million times greater, or .0000000004226 compared with common air, or .000000061 compared with hydrogen.

*If v and v' represent the velocities at Neptune and on the periphery of the nebula, and r and r' the radii of revolution, then by the principle of equal areas,

$v^2 : v'^2 :: r' : r$, whence $v'^2 = v^2 \frac{r}{r'} = v^2 \frac{r}{100r} = \frac{v^2}{100}$, and $v' = \frac{1}{10} v$.

thus, temporarily, it is true, that is, so long as the homogeneity of the nebula shall endure,* an abstract conception of central forces, the consequences of which have been discussed in treatises on mechanics since the time when Newton signalized it as a law fully as capable of binding harmoniously the movements of a system as that of gravity varying in the inverse ratio of the square of the distance. At that time all bodies placed within that vast circumference would describe, under the slightest impulse, ellipses or circles having their centre at the centre of the nebula.† For all these bodies the period of revolution would be the same, a thousand times greater than that of Neptune.‡ A molecule falling from any point whatever toward the centre would reach it in a quarter of that time, that is to say, in 41,000 years.

"This nebula moves. We find in the translation of the sun toward the constellation Hercules, the movement of its centre of gravity. The total movement must be more complex, and embrace a slow rotation or rather a sort of whirlpool motion of the whole mass around a certain axis, as in the nebulæ of Lord Rosse. But it is only in the plane centrally perpendicular to this axis that these rotations could become regular and persistent, because there

* The principle would not be disturbed by any rate of increase of density, provided it proceeded symmetrically on all sides at corresponding distances from the centre.

† See Tait and Steele's *Dynamics of a Particle*, 4th ed., 114.

‡ Orbital velocities are always proportional to the central force. Therefore, if v, r and t represent the velocity, distance and time of any revolving body, then since in this case velocities are proportional to the distances and inversely as the times, we may take nr, nr and $\frac{1}{nt}$ to represent the velocity, distance and time of any other body revolving as assumed. Therefore, $\frac{v}{nv}=\frac{r}{nr}=\frac{nt}{t}$ or $\frac{1}{n}=\frac{n}{1}$. $\therefore n=1$, and $nt=t$; so that the times of revolution of all bodies moving as supposed would be equal. But the times, under the law of gravity, are as the cubes of the square roots of the distances; and for the distances r and $100\,r$, are as 1 to $100^{\frac{3}{2}}$, or as 1 to 1000. Hence the uniform time of revolution would be a thousand times the period of Neptune.

they would adjust themselves according to the same laws as a circulation regulated by the proper gravity of the system, that is to say, of all the parts. If, then, trains of matter somewhat circular, in a word, rings like those of Saturn, or those of certain nebulæ, such as 51 Messier, become finally established in the bosom of the nebula (2), in the vicinity of the primordial equator, the velocity must have increased from the internal border of each ring to the external, proportionally to the distance from the centre, as in the case of the rotation of a solid ring.

"All the planets proceeding from the rupture of these rings would continue to circulate in the primitive direction, which we will call *direct*. Here is the capital fact of which the hypothesis of Laplace takes so good account. Only, their rotations should all be direct, if things remained in this state. But from the commencement, I mean to say from the time when this nebula became completely isolated, there has been produced a phenomenon which has modified these first conditions. From all the regions which do not participate in these regular circulations, the materials of the nebula fall toward the centre, describing very elongated ellipses (3), and not circles. They produce there a gradual progressive condensation, in such a way that, disregarding a multitude of partial movements, the density of the nebula ceases to be uniform, and finally arrives at a regular rate of increase from the surface to the centre."

M. Faye next proceeds to determine the direction of the rotation in this nebulous mass at different distances from the centre, and deduces an expression for the velocity which at certain distances from the centre gives direct motion; at greater distances, a diminished velocity in the same direction; at a certain greater distance, no motion, and at all distances still greater, a retrograde motion con-

tinuing to increase in velocity to the surface.* "Thus," he says, "the nebula during the entire period of concentration is divided into two regions very different: (*a*) The exterior, where the rings in giving birth to planets, will impress upon them a retrograde rotation, like that of Uranus or Neptune; (*b*) The interior, where the planets will all have a direct motion, like Saturn, Jupiter, etc. This is the singular phenomenon which our system presents, and against which the hypothesis of Laplace opposes itself (4). It is thus bound to a simple increase of density from the border to the centre of the nebula. Without doubt things might happen otherwise. If the rings had a preponderant mass, they would attract to themselves all the matter, and would finally vacate the central regions, as in the nebula of the Lyre.

"The system thus formed is by no means complete. It occupies at first a space much greater than our actual system; but in subsequent times, central condensation continually progresses, not by cooling, be it well understood, but by the continued action of gravity. The planetary orbits were at first plunged in the diffused and rare mass of the nebula. By degrees this mass withdrew from the regions exterior to the orbits, and proceeded to concentrate in the interior, toward the centre of these same orbits. The areas described in a given time in these circulations will not for this reason change, but the rings or the planets

* The expression adopted for the law of density (see also p. 128) is

$$D\left(1-\beta\sqrt[n]{\frac{r}{R}}\right)$$

The square of the linear velocity of the circulatory movement is

$$4\pi f D\left(\tfrac{1}{3}r^2-\frac{n\beta}{1+3n}\sqrt[n]{\frac{r}{R}}\,r^2\right)$$

An inspection of the factor in parenthesis shows that with increase of r the negative term increases more rapidly than the positive term. While it remains smaller, the value of the whole expression is positive, and this denotes direct motion; when it equals the first term, the value of the whole expression is zero, and when it exceeds the first term, the whole expression becomes negative, which means that the direction of the motion is retrograde.

will gradually approach the centre, and their velocity will be continually accelerated, conformably to the theory which Laplace has given in the fourth volume of the *Mécanique Céleste*, for the inverse case where the central mass goes on diminishing. Here we are not concerned with minute effects, since it is almost the entire mass of the nebula, up to about $\frac{1}{100}$, which marches thus in space from orbit to orbit, to gather itself at the centre. To this is added another cause, which acts exactly in the same manner, that is to say, the resistance of the materials which constantly travel through space, and fall almost directly toward the sun, and from nearly all sides. It is further evident that this double and continual contraction of the orbits will proceed, without altering in any respect the direction of the rotation of the planets or the direction of the circulation of their satellites.

"As to the distances of the planets from the sun, or of the satellites from their planets, nothing prevents that they should be found to-day, beyond the limits assigned by Laplace. There is no more question, in fact, in causing to intervene here the play of centrifugal force for producing some at the expense of others.

"We have assumed that the sun absorbed *all* that which was not involved in the circulation of the rings in the vicinity of the primitive equator. This could not be completely the case. A portion of the superficial nebulosities, especially toward the poles, actuated by very feeble lateral impulsions through the influence of various causes, and describing around the centre very elongated ellipses, must have been able to traverse the central regions without being arrested there. Escaped from the agglomeration where the sun at a later period is formed, they have nevertheless experienced its action in numerous returns, and must have continued to describe elongated trajectories, variable in form and position, whose final term will be an

ellipse having its focus in the place where the primitive ellipse had its centre. Undoubtedly, here is presented the difficulty of the rapid contraction which the circular orbits have undergone; but as these portions move in elongated ellipses, reaching or even passing the limits of the nebula, they must have escaped almost completely this effect, since one part of their orbits lay, since their origin, beyond the region whence the mass withdrew (5). The period of revolution must have remained very considerable, and must have been reckoned by thousands of years, as in the primitive times. As to the direction of the movement, it will be indifferently, direct or retrograde; the inclination of the planes of the orbits to the primitive equator will be any value whatever; in a word, this will be the realm of the comets, which appertain so visibly to the solar system, though the hypothesis of Laplace would be compelled to exclude them.

"However it may be on this delicate point, our system became stable from the epoch when that part of the nebula not involved in the planets became entirely absorbed in the sun. The void has been made complete, as about the simple or double stars which we see in a dark night. It remains to expend the energy transformed into heat; but that which has conserved the method of the movement will remain.

"This conservation, nevertheless, is not absolute. Attractions provoke in all bodies internal strains which develop a little heat. Cometary masses passing near the sun disintegrate into nebulous trains as if for return to their origin. These latter proceed to collide with planets and engender there light and heat. Thus disappears by degrees a portion of the store of mechanical energy but this is only a feeble image of the past.

"It remains to restore to the starting point this mysterious dissemination of dark matter which contains in

potentiality so many wonders; but this must remain the insuperable term which we meet in all questions of origins. Nevertheless, the possibility cannot be denied. The repulsive force of the sun which I have attributed to the action of incandescent surfaces, and where other astronomers see the play of electric forces, produces *before our eyes*, in the extremely divided matter of comets, though in miniature, a dissemination entirely parallel.

"I ask for this rapid exposition, the indulgence of the Academy, for I am sensible how far it is from the incomparable precision which we admire in the hypothesis of Laplace. Since the latter was formulated, the two Herschels with their powerful telescopes, the American astronomers with their gigantic lenses, have taught us to read the heavens better. Spectral analysis and thermodynamics have been created. In short, Laplace was unacquainted with the new conditions which observation has continued to reveal to us down to the most recent times. I have thought that the moment had arrived for attempting to bring all these facts into coördination."*

It will be noticed that most of the fundamental assumptions of this theory are in accord with the positions taken in this work. That the different nebulæ are destined to different methods of evolution I have maintained in the first chapter. The likeness of the stellar firmament to the assemblage of variously aged trees in a forest is an analogy pointed out by Laplace. I have argued, and so has Mr. Croll, that the heat of incandescent nebulæ may be the result of the transformation of mechanical energy; and I have pointed out reasons for presuming that incandescent nebulous matter existed previously in a cold and dark state. M. Faye does not hesitate to recognize with

* See also M. Faye's *Note sur les idées cosmogoniques de Kant, à propos d'une réclamation de priorité de M. Schlötel*, Comptes Rendus, xc, 1246, May 31, 1880.

Laplace, that nebular equatorial rings will undergo disruption, though the rings are conceived by him to be formed within the nebular mass, and not at its periphery. The descent of the parts of the nebula toward the centre by virtue of their own gravitation, is a doctrine generally admitted, though M. Faye assumes that other neighboring parts are not thus moved. That the whole nebula might be transformed into a ring is a conclusion which I have enunciated, and on different grounds. M. Faye recognizes the influence of meteoroidal matter in condensation, and the production of heat and light by collision with the planets; and is the first after the present writer, so far as known, to suggest that attractions "provoke internal strains which develop a little heat;" though his statement is a single sentence, and does not reveal any high estimate of the theoretical importance of the principle.

At the same time, however, M. Faye's noteworthy modification of nebular cosmogony embodies some statements and principles on which I would like to offer a few special observations:

(1.) The circumstance that Laplace offered no explanation of the heat postulated in the primitive nebula ought not to weigh against the plausibility of his theory. As M. Faye observes, we always arrive sooner or later at questions of origins which, for the time being, must remain unanswered. M. Faye himself has assumed more unexplained conditions than Laplace. If the latter finds evidence of the primitive existence of intense heat, its inexplicability is no greater evidence against its reality than the mystery of the *aurora borealis* against the reality of that phenomenon. Nor was Laplace consigned to the alternative of accepting Poisson's hypothesis. He may have rejected it as improbable, and have trusted to the future to disclose a physical cause of the heat. Poisson's hypothesis was not reached by an unbroken process of scientific deduction; it

was a hypothesis created outright by the power of invention. The incandescent nebula of Laplace was a state disclosed to intelligence by a rational regressive process of argumentation.

(2.) As to the establishment of rings "in the bosom of the nebula," it will be noticed that M. Faye does not assert the probability of its occurrence, or mention any physical ground on which it could be predicated, but simply says, "if they should become finally established," the angular velocity would be the same on both borders. Now a spiral motion, as I have conceived, implies a retarding influence exerted upon the exterior portions of a fluid in a state of rotation. While a fluid mass possessing a spiral motion must tend toward a symmetrically spheroidal form, the production of our annulus can only be a peripheral incident; and it is certain that we know of no physical cause for its existence except that assigned by the theory of Laplace. A "whirlpool" motion may be considered to differ in direction from the spiral motion here contemplated. The paths described have the same form, but the parts converge by a winding progress toward the centre. They are conceived as descending by a retarded motion at the same time that some impulsion has deflected them from direct lines to the centre. Admitting that "trains" of particles might be able to extricate and isolate themselves sufficiently from the opposing friction of contiguous regions of particles, so as to flow like streams in the ocean, with a differentiated and special motion; admitting also, that the nebula as a whole possesses some rotary motion, and that the rate of this increases as the parts descend nearer the centre, what can we infer on physical grounds, as to the formation of rings? We cannot look for them as a result of motion toward the centre; this tends continually to prevent rings. We cannot expect them to result from local tangential impulsions producing currents which flow around

the mass; for by hypothesis, circumferential motion is all the time combined with motion of descent; and besides, the differential motion of such currents would be destroyed by friction, and the currents would cease to exist; and finally, if they should persist, the planes of the paths described would sustain no common relation to a fixed plane. Rotation of the mass would exert no influence upon the trains of particles except through the development of centrifugal tendencies. These would be greatest at remoter distances from the axis of rotation, that is, in the regions where the linear motion under the law of attraction within a sphere would be greatest. In other words, the greatest velocity of descent would be opposed by the greatest contrary tendency; the motion in the descending spiral would be somewhat equalized, and the form of the spiral would more nearly approach a circle. Now, it is conceivable that the relative amount of the centrifugal tendency might become so great that the motion of descent would be practically zero, and a train at the equator would pass into the form of a ring. But such ring results, it will be noticed, from a suspension of the motion of descent, which is a cardinal conception in M. Faye's theory at this point, and also in relation to cometic genesis; and assumes the controlling influence of the centrifugal tendency. In both these requirements the conditions of annulation become exactly those assumed in the Laplacean theory. It is not affirmed that M. Faye reasons or would reason in this way in following out the genesis of a ring. He does not explain by what physical action a ring would arise; and all that is here stated is that if a ring could come into existence in a "whirlpool" nebula, it would be only through centrifugal action, and must be peripheral and equatorial, as Kant and Laplace assumed. Thus, when M. Faye's theory is pushed through the details of ring-genesis, its

peculiarities avail nothing, and it invokes the Laplacean principle to carry on the cosmogonic work.

(3.) It is not apparent that portions of matter falling from the regions of the poles of the nebula through a medium in which attraction varies as the distance from the centre, would necessarily describe "elongated ellipses." Though this is a correct physical principle, and might be realized in a hollow sphere, it would not be within a nebulous sphere. The descending matter would, from the assumed homogeneity of the nebula, possess a physical state somewhat similar to that of the matter passed through. Its motion would therefore be retarded by friction, and approximated to the motion of the medium by which it might be surrounded. But supposing those elliptic motions accomplished, any condensation of the nebula arising from the motion of these portions of matter toward the centre would be neutralized by the succeeding motion of the same portions of matter away from the centre. This is not to deny that condensation would take place, but only that the existence of "elongated elliptic orbits" would contribute to condensation. The "regular rate of increase" of density toward the centre would result from the consentaneous movement of parts from the more peripheral regions along lines more or less disturbed, toward the centre of gravity of the mass.

(4.) On M. Faye's reasoning to establish the necessity of retrograde motions in the parts of the system remotest from the centre, I have had occasion to offer some observations in another place.* I have also attempted to show that by properly supplementing the Laplacean conception, retrograde motions are provided for as well as direct motions.

(5.) M. Faye's speculation concerning the origin of comets seems particularly inconclusive. He undertakes

* Part I, Chap. II, § 4, 2; and Part II, Chap. I, § 2, 1, (4).

in the first place, a task unnecessarily imposed, since it may be rationally maintained that the comets are not native members of our system. He proceeds, in the next place, in a wholesale and incautious way to consider the cometary masses as *parts* of the nebula, and then speaks of them as "reaching or even *passing*" the limits of the nebula, and next states that "one part of their orbits lay *since their origin, beyond the region whence the mass withdrew.*" The self-contradiction here is palpable, and becomes a physical absurdity when we reflect that M. Faye attributes to an origin within the original limits of our nebula, cometary masses which retire to enormous distances beyond any supposable limits reached by the primitive nebula, and even traverse our system with velocities greater than could be acquired by the action of central forces native to the system.

While, therefore, deeply impressed by the learned ingenuity of M. Faye's modification of nebular cosmogony, I do not as yet feel prepared to give it a preference over that based on strict Laplacean conceptions.

2. *Spiller's Proposed Modification.*— It seems desirable also to notice a modification of nebular theory advanced by Spiller of Berlin.* He dissents from the theory of the formation of planets through the intervention of rings. According to his view planets are the product of tidal action combined with centrifugal tendency. This action is exerted upon the central mass after reaching the condition of igneous fluidity. It is manifest that a separated planetary mass must produce a tidal swell of some magnitude upon the fluid central mass. This tide would be turned always in the direction of the planet—an antitide

* Philipp Spiller: *Die Weltschöpfung vom Standpunkte der heutigen Wissenschaft. Mit neuen Untersuchungen*, 1868, 2d ed. 1873; *Die Entstehung der Welt und die Einheit der Naturkräfte. Populäre Kosmogonie.* See also the same writer's important work. *Die Urkraft des Weltalls nach ihrem Wesen und Wirken auf allen Naturgebieten. Für Gebildete jeden Standes.* 374 pp. Berlin, 1879.

moving simultaneously on the opposite side. It is manifest also that the magnitude of the tide would increase with the proximity of the planet, and still further with the conjunction of two or more planets. At some perihelion of the planet, therefore, — concurring perhaps with a conjunction of planets — the centrifugal tendency of the equatorial portion of the central fluid mass would exceed gravitation, and the tidal swell would be lifted bodily from connection with the central mass and move centrifugally to such distance that a state of equilibrium would be reached. The mass thus detached would at once assume a spheroidal planetary form. Thus it is supposed Uranus was detached as a tidal swell raised by the attraction of Neptune; Saturn, by a similar action of Uranus, and so on. As to Neptune, it must be admitted that the separation took place solely through the tangential momentum at the equator of the original mass, or it must be presumed that a tidal effect was produced by the presence of some external body.*

This theory possesses the merit of explaining the ellipticity of the planetary orbits as a primary result, and of dispensing with rings and thus avoiding the problem of planetation from rings. But on the contrary it encounters great difficulties. It is necessary to show the probability of the non-formation of rings during the nebulous stage, or else to explain their subsequent disappearance without the production of planetary bodies. It is also necessary to show that the central mass ever possessed such velocity of rotation as to detach a tidal swell from a liquid spheroid — a difficulty increased by the comparative insignificance of such a swell on a body possessing the relative mass of the sun. But the greatest difficulty is presented by the fact that

*The reader will note that Spiller's conception is the prototype of Mr. G. H. Darwin's (noticed hereafter) concerning the retirement of the lunar mass from the semi-fluid earth.

the sun has not yet attained a liquid condition, according to the views of modern astronomers, and there is no likelihood that its temperature had subsided to any lower point than the present at any epoch in the past. While therefore, Herr Spiller has offered a theory which is thinkable and consistent with the laws of nature, it does not seem to be one which represents the actual history of nature.*

*The writer intended to notice the seemingly important work of M. Roche, entitled *Sur l'origine du Système Solaire*, published by Gauthier-Villars, Paris, 1873, but though ordered repeatedly from booksellers in Paris, Berlin and Leipzig, no copy of it has been obtained.

CHAPTER II.

GENERAL COSMOGONIC CONDITIONS ON A COOLING PLANET.

Und ob Alles im ewigen Wechsel Kreist
Es beharret im Wechsel ein ruhiger Geist.—SCHILLER.

Opinionum commenta delet dies, naturæ judicia confirmat.
CICERO, *de Nat. Deor.*

§ 1. RELATIVE AGES OF PLANETS IN A SYSTEM.

ACCORDING to the nebular theory here accepted, the ages of the planets must be graduated according to their distances from the sun. The remotest planet at present known is Neptune. Its existence, before discovered, was pointed out by certain perturbations in the next interior planets, which were not fully accounted for by the attractions of any known body. There still remain some residual disturbances which have led to the conjecture that a still remoter planet exists. This opinion was shared by my late honored colleague, Professor James C. Watson. For similar reasons Mercury for many years has been doubtfully regarded as the most interior planet. Dr. Lescarbault announced that such planet had actually fallen under his observation, and he designated it Vulcan. But other observers were not able to verify the alleged discovery. During the total eclipse of July 29, 1878, Professor Watson, in charge of observations in Wyoming, devoted his entire attention to the search for intra-Mercurial planets, and succeeded in satisfying himself that one or two came

within the range of his instrument.* Professor Lewis Swift also reported from Denver some similar observations.† The great difficulty of exact determinations during the few seconds of totality of an eclipse, and the absence of other corroborative observations, have led many astronomers to adhere to the opinion that Professors Watson and Swift mistook fixed stars for planets.

But the *stage of development* of a planet does not depend alone on its age. Planetary evolutions rest finally on progressive cooling. The condition of a planet as a whole is determined by the temperature of the mass. After incrustation, the state of the surface depends less and less upon the temperature of the interior, since the rate of conduction of interior heat through the crust continually diminishes. But a large mass, other things being the same, retains a high temperature longer than a smaller one. A small planet may become totally refrigerated, while a large one of greater age may linger in a state of self-luminosity. The length of time the heat of a planetary body will endure, depends, then, on mass and extent of radiating surface. As the ratio of the masses is greater than that of the surfaces, the relative length of time a particular phase will endure is greater than is indicated by the relative masses of the planets. In other words, if one planet has twice the mass of another, their densities being the same, the duration of a certain phase of cooling will be more than twice as long as in the other.‡

* See his communications in *Amer. Jour. Sci.* III, xvi, 230–3, 310–13, Sept. and Oct., 1878.

† L. Swift, *Amer. Jour. Sci.* III, xvi, 313–15. See also, *Science*, 26 Feb. and 23 Apr. 1881.

‡ If Δ and Δ' represent the rates of radiation of two planets, r and r', their radii, H and H′ the total heat in the two, and ρ and ρ' their respective densities; then since the rates of radiation are as the surfaces,

$$\Delta : \Delta' :: r^2 : r'^2 \; ; \; \therefore \Delta' = \frac{\Delta\, r'^2}{r^2}.$$

And since the total amounts of heat are as the masses,

$$H : H' :: \rho r^3 : \rho' r'^3 \; ; \; \therefore H' = \frac{H\, \rho' r'^3}{\rho r^3}.$$

§ 2. PASSAGE TO THE MOLTEN PHASE.

A planetary body is to be conceived as existing, at a certain epoch, in a state of fire-mist. In this state a portion of the matter exists in minute liquid particles which are held in suspension in the gases which constitute the remaining portion. Some chemical compounds probably exist, but others, evidently, are still prevented by the intense heat from forming. The gases, deeply seated beneath the surface, are subjected to an enormous pressure which reduces them to a density approaching that of the liquefied material, or even exceeding it. At some epoch the molten matter must descend toward the centre until it reaches a zone where its density is equalled by the density of the compressed gases. If this zone of liquid precipitation is distant from the centre, it will gradually subside toward the centre, in proportion as heat escapes from the condensed gas, and it thus passes, under the enormous pressure, into the liquid state. Ultimately, therefore, the planet will consist of a liquid nucleus surrounded by an atmospheric fire-mist yet too intensely heated to permit all its constituents to pass out of the aëriform condition. Progressively, however, the atmospheric envelope will transfer itself by precipitation to the liquefied nucleus. Meantime some portion of the atmospheric constituents will retain their gaseous condition below any temperature which we have experienced. The result will be a molten globe surrounded by an aëriform atmosphere.

If T represent the relative time reqnired for a planet to pass through a certain phase of cooling, then

$$T = \frac{H}{\Delta}.$$

In this expression, since H varies (the density remaining the same) as the cnbe of the radius, and Δ, as the sqnare of the radius, it follows that T varies more rapidly than the mass of the planet. We may also deduce

$$T' = T\frac{\rho'}{\rho} \cdot \frac{r'}{r}.$$

§ 3. SUPERFICIAL SOLIDIFICATION FROM COOLING.

At a certain temperature of the molten sea, certain compounds will begin to solidify in crystalline forms. These will float in the liquid magma, in accordance with a principle which I venture to regard as a general law of matter. Many substances, in passing from a liquid to a solid state, slightly increase in bulk. This is notoriously true of water and ice, and of type-metal. It is also true that solid lava floats on molten lava, a notable instance of which we have in the crater of Kilauea, solid glass on molten glass, and solid iron on molten iron. It is quite true, however, that a piece of iron may be taken so cold that its density exceeds that of molten iron, in which case it will at first sink. But after becoming heated and expanded, and long before the fusing temperature is reached, the iron will rise to the surface.* It is hardly to be doubted, therefore, that solidification from cooling would begin on the surface and gradually extend downward.†

*On floating iron, see *College Courant*, 13 Apr., 1872, p, 173; *Nature*, May 10, 1877, 23; 8 Aug., 1878, 397, for conclusive experiments; 29 Aug. 1878, 464 and vol. xvi, 23. For Mallet's apparently conflicting results, see *Nature*, No. 156, abstract in *Amer. Jour. Sci.*, III, viii, 212, and for a reply to Mallet, see A. Schmidt, *Amer. Jour. Sci.*, III, viii, 287. Compare, also, Sir William Thomson, *Trans. Geol. Soc.*, Glasgow, vi, 40, 14 Feb., 1878. Some recent experiments show that molten steel has a specific gravity of 8.05, while cold steel is 7.85 (*Nature*, xxvi, 138, June 8, 1882). On floating lava, see Scrope: *Volcanoes*, 84, 477; Kaemtz: *Meteorology*, 152; G. P. Marsh: *Man and Nature*, 545; Miss Bird: *Hawaiian Archipelago;* *Nature*, xi, 324; Miss C. F. Gordon-Cumming: *Fire-Fountains, the Kingdom of Hawaii*, etc., 2 vols., 8vo., 1883. On experiments with "Rowley Rag," see *Chemical News*, xviii, 191.

†Sir William Thomson, nevertheless, entertains the opinion that solidifying masses would sink to the centre; and he has enunciated, in harmony with Hopkins, the somewhat fantastic theory that the sunken masses would build up a honey-combed structure to the surface, and "masses falling from the roofs of vesicles or tunnels," might produce earthquake shocks: *Secular Cooling of the Earth*, Trans. Roy. Soc., Edinb., 1862; Thomson and Tait's *Natural Philosophy*, §§ (*ee*), (*ff*); *Glasgow Address*, 1876, *Amer. Jour. Sci.*, III, xii, 346-7; *Trans. Geol. Soc., Glasgow*, vi, 40-1, 14 Feb., 1878. In the latter paper, however, he expresses himself with less confidence. On this subject see Hopkins: *Researches in Physical Geology;* Phil. Trans. Roy. Soc., Pt. II, 1839, quoted in his *Report to British Assoc.*, 1847, p. 33.

As a final illustration, I venture to quote from Mr. W. Matthieu Williams* a description of what takes place in the "open hearth finery and the refining of pig-iron." "Here a metallic mixture of iron, silicon, carbon, sulphur, etc., is simply fused and exposed to the superficial action of atmospheric air. What is the result? Oxidation of the more oxidizable constituents takes place, and these oxides at once arrange themselves according to their specific gravities. The oxidized carbon forms atmospheric matter and rises above all as carbonic acid, then the oxidized silicon being lighter than iron floats above that and combines with aluminium or calcium that may have been in the pig and with some of the iron; thus forming a silicious crust closely resembling the predominating material of the earth's crust.

"When the oxidation in the finery is carried far enough the melted material is tapped out into a rectangular basin or mould, usually about ten feet long and about three feet wide, where it settles and cools. During this cooling the silica and silicates—*i.e.*, the rock matter—separate from the metallic matter and solidify on the surface as a thin crust, which behaves in a very interesting and instructive manner. At first a mere skin is formed. This gradually thickens, and as it thickens and cools, becomes corrugated into mountain chains and valleys much higher and deeper in proportion to the whole mass than the mountain chains and valleys of our planet. After this crust has thickened to a certain extent, volcanic action commences. Rifts, dykes and faults are formed by the shrinkage of the metal below, and streams of lava are ejected. Here and there these lava streams accumulate around their vent and form isolated conical volcanic mountains with decided craters, from which the eruption continues for some time. These

* Williams: *Discussions in Current Science*, ch. vii, "Humboldt Library," No. 41, p. 25, Feb., 1883.

volcanoes are relatively far higher than Chimborazo." The materials of the fire-formed crust of a planet must similarly pass through the stages of oxidation and silication, and the incidents of progressive cooling must be fairly represented by the phenomenon above described.

§ 4. INTERNAL SOLIDIFICATION FROM PRESSURE.

While incrustation begins, or even long before it begins, solidification may be produced in the central regions, in a planetary mass sufficiently large, by the great pressure of the superincumbent portions. But in recognizing the probability of a solid central portion, it must not be supposed that the matter is less hot than if a molten liquid. Any portion of such solidified interior, if brought to the surface, would be instantly liquefied. But at some point between the centre and the surface, the condensation may not be sufficient to produce solidification, and the reduction of temperature may not be sufficient to cause it. There would then be a liquid zone interposed between a solid crust and a solid nucleus. That zone might be so thin and so variable in its thickness as to suffer actual interruption of continuity. It would then exist as separate lakes in regions more or less removed from each other, and the rigidity of the planet would be very nearly such as is due to complete solidification. But even if a solid crust were separated from a solid nucleus by a continuous liquid zone, it does not appear to me that under the actions of the planetary system, the planet would be wanting in any of the astronomical properties of complete solidity. I do not conceive that the crust would be likely to slip around the core, since, whatever action should be exerted upon the crust would be exerted correspondingly on the parts beneath the crust. The several interior zones in a rotating oblate spheroid, would present the same rela-

tive equatorial protuberance as the external zone, and would all be moved synchronously and proportionally.

The liquid zone would not pass by an abrupt transition downward into the state of the solid core; but would present gradually increasing degrees of viscosity. The same might be true of the passage upward into the solid crust.

Whether a liquid zone should exist or not, it is apparent that in case of the removal or diminution of the pressure over any portion solidified by pressure, this would instantly be followed by the liquefaction of such portion. Hence a deep fissure through the external crust might be followed by the passage of large volumes from the solid to the liquid state.*

§ 5. MAXIMUM INTERNAL TEMPERATURE OF AN INCRUSTED PLANET.

The progress of cooling, down to the time of the first incrustation, would be promoted by a convective circulation between the central and peripheral parts, or, in case of central solidification, between the solid core and the periphery. The effect would be to equalize the temperature of all parts of the planetary mass.† It might be supposed, therefore, that at the epoch of first incrustation the whole temperature would be but little above the point at which solidification from cooling might begin. Thus the maximum temperature of the heated interior of a planet might be conceived to be about that at which the matter of the planet liquefies under the atmospheric pressure on the planet's surface. As a larger planet implies both a greater mass of atmosphere and an intenser gravitating

*These matters will be more particularly discussed in treating of the earth.

† Sir William Thomson has shown that if the rate of increase of temperature in penetrating the earth should be found to suffer a diminution at greater depths than have been as yet explored, this fact would imply a uniform internal temperature below a certain depth (*Trans. Geo. Soc., Glasgow*, vi, 45).

power, both causes would increase atmospheric pressure, and hence lower the temperature at which incrustation would begin. This implies that the central portion of a large planet is less hot, and must consequently require a shorter period for cooling, aside from the consequence of a greater amount of heat to be radiated. Inferior density would operate in the same direction. For these two reasons, therefore, the larger planet should not linger proportionately long in the highly heated stages.

§ 6. TIDAL ACTION AND ITS CONSEQUENCES IN PLANETARY HISTORY.

I believe that the geologist who had studied all the text-books in existence might still be unacquainted with the very modern researches [on palæozoic high tides] which I am attempting to set forth. Yet it seems to me that the geologists must quickly take heed of these researches. They have the most startling and important bearing on the prevailing creeds in geology. One of the principal creeds they absolutely demolish.—Prof. R. S. BALL: *Nature*, Dec. 1, 1881.

The ebb and flow of the tidal wave, therefore, consists not only in an alternate rising and falling of the waters, but also in a slow, progressive motion from east to west. The tidal wave produces a general western current in the ocean.—J. R. MAYER: *Celestial Dynamics*.

1. *Some Elementary Principles.*—The influences of cosmical tides are various, important, and everywhere felt. Tidal movements are as universal as gravitation itself; and late researches have shown that cosmic tides have been deeply concerned in the establishment of the planetary relations observed in our system. A tide may be defined as the prolateness of a body resulting from the attraction of another body. As no matter is known to exist which is absolutely rigid and incompressible, there can be no state of solidity so absolute as to be exempt from the liability to tidal deformation under the gravitational power of cosmic masses. Between absolute solidity and perfect molecular mobility exist all grades of consistency, from ordinary solidity through the various degrees

of viscosity, liquidity and gaseity. These various conditions of matter are themselves relative to pressure, temperature and gravitation; since, at a given pressure, all substances pass, with increase of temperature to the liquid and aëriform conditions; and at a given temperature, however high (within certain limits), all substances pass, with increase of pressure, to the liquid and solid conditions; and at given pressure and temperature, all substances tend more and more, under increase of gravity, to behave like liquids, and under diminution of gravity, to behave like gases. Moreover, there is no solidity so complete that in the presence of the mighty forces of nature, the substance does not yield like the simplest liquid. In fact, it may well be doubted whether the attractions exerted by the sun and planets feel to a very important extent, a difference in the resistances offered by the solid and liquid states upon the bodies subject to their influence. The most stubborn granites, diorites and quartzites may probably be conceived as fluids in relation to all the greater cosmic forces.*

Tidal results depend upon the unequal influences exerted by an attracting body upon the nearer and remoter parts of the body influenced. The attraction exerted by one body upon another produces the same total result as if the whole force were applied at the centre of gravity. But meantime, the different parts of the affected body will be set in motion in respect to each other, because, being at different distances from the attracting body, they are acted on with different intensities of force. The parts nearest the attracting body will be more strongly influenced than the more central parts, and will consequently manifest a stronger tendency than the more cen-

*For an impressive view of the magnitude of such forces, see an article by C. B. Warring, in *Pop. Sci. Monthly*, xvii, 612-8, Sep., 1880, and a similar one by E. L. Larkin, in *Kansas City Rev. of Sci. and Industry*, vii, 96-9, June, 1883.

tral parts toward the attracting body. They will begin to retire from the more central parts, and will actually move away from them until restrained by the cohesion of all the parts with each other, and by the tendency of all masses of matter to retain the spherical form. The restraining influence of the last-named tendency is the same for all states of matter where the mass is the same; but the restraining influence of mutual cohesion of parts varies with the state of the matter. A given attraction will therefore produce a greater tidal result in an aëriform or liquid body than in one which is viscid or nominally solid.

But further, the central parts of a body influenced by a tidal attraction yield more than the remotest parts. They tend, therefore, to leave the remotest parts behind, and these become drawn out into a retral prolongation until restrained and held down by mutual cohesions and the law of sphericity. We have, therefore, a tidal protuberance on two opposite sides of the body, produced simultaneously. They are a *tide* and an *anti-tide*. The two tidal curves are similar; they are produced by the same forces, but the curve of the anti-tide is reversed in respect to the curve of the tide. The force raising it is a *deficient* attraction; it is virtually a force acting in the *opposite* direction from the real attraction. In short, the anti-tide may be conceived as produced by the attraction of another body situated on the side opposite the real tide-producing body; and this may be designated the anti-tide-producer.

The anti-tide, however, is somewhat less than the tide. The excess of attraction producing the tide is greater than the deficiency of attraction producing the anti-tide. This would not be the case if the attraction diminished simply with increase of distance. Attraction diminishes with increase of the *square of the distance*.

There are three conceivable general cases under which

tidal actions may be exerted.* (1.) Where the tide-bearing body is homogeneous, or varying in density toward the centre according to some fixed law. Here every

*The statements made in the present connection on the subject of tides, embrace only such generalities as concern the main course of planetary evolution. Any particular case, like the oceanic tides on the earth, may involve numerous considerations of which no account is necessary here — such as variations in distance of tide-producer; changes in declination in reference to equator of tide-bearer; interferences of tidal actions of two or more tide-producers; consequences of different rates of change of right ascension of different tide-producers; the absolute angular velocity of the tide-producer in its orbit; rotation and oblateness of tide-bearer; depth and variations in depth of enveloping film; relative density of film, its actual index of viscosity, its actual density and its friction against resistances. In our general view it will only be necessary to regard the relative tidal efficiency of the tide-producer, the relative mass and volume (radius and density) of the tide-bearer, and the general fact of axial and orbital movements.

No theory of tides has been mathematically worked out, which answers all the requirements of tidal phenomena in the terrestrial waters. The fundamental conceptions embodied in the "Equilibrium Theory" of Newton and Daniel Bernoulli are undoubtedly correct; but this theory neglects many modifying conditions in the actual case, and therefore fails in many particulars. But it is not just to pronounce it "contemptible," as Sir G. B. Airy has done. The "Dynamical Theory" of Laplace, generally considered more rational, though also severely criticised, conceives each particle of the water in motion, and investigates the forces acting on it. The tidal swell results from the flow of water on both sides toward it, and the ebb results from the flow in both directions away from it. The working out of the theory, however, has to assume, contrary to the facts, that the earth is completely covered with water, and that it is of uniform depth throughout any parallel of latitude. The "Wave Theory," expounded by Sir G. B. Airy, is based on the laws of movement of waves along canals relatively shallow and narrow, and applies especially to the motion of tidal waters in shallows, estuaries and rivers, where the other theories fail; but for the phenomena of the open sea, it makes the false assumption that the wave is restricted to narrow canals, instead of spreading freely in all directions. For our present use, the conceptions of the Equilibrium Theory are entirely adequate.

The completest general exposition of tidal theories may be found in Airy's article on Tides and Waves, in *Encyclopædia Metropolitana*, vol. v, pp. 241*-396*. For the purposes of the general student, however, a much more satisfactory general exposition may be found in the *Appendix* to *Johnson's Cyclopædia*, by Gen. J. G. Barnard. See also, Prof. Wm. Ferrel's *Tidal Researches*, Appendix to U. S. Coast Survey, 1874, or thereabouts. See also, as collateral, Ferrel's papers on the *Motions of Fluids and Solids Relative to the Earth's Surface*, in eight communications to the Mathematical Monthly, Cambridge, Mass., 1859-60, vols. i and ii; also, his *Methods and Results of Meteorological Researches, for the Use of the Coast Pilot*, Part I, 1877, Part II, 1880 (on Cyclones, Waterspouts and Tornadoes).

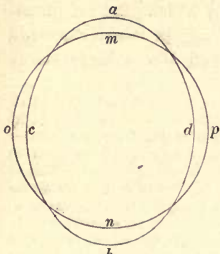

FIG 37.—DEFORMATIVE TIDE.

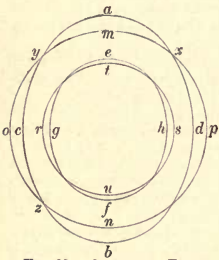

FIG. 38.—COMPOUND TIDE.

am, tidal elevation in less viscous envelope.

oc, tidal depression in less viscous envelope.

et, tidal elevation in more viscous nucleus.

rg, tidal depression in more viscous nucleus.

mt, depth of envelope at mean tide.

at, depth of envelope at high tide over nucleus supposed rigid.

ae, depth of envelope at high tide over yielding nucleus $= at - et$.

cr, depth of envelope at low tide over nucleus supposed rigid

eg, depth of envelope at low tide over yielding nucleus $= cr + rg$.

successive layer undergoes tidal disturbance according to its distance from the centre. The whole body is, therefore, symmetrically transformed, and becomes a prolate spheroid, with a prolate axis $a\,b$, Figure 37, varying inversely as the coefficient of viscosity. This we will designate a *deformative tide.* Here $m\,o\,n\,p$ is a section of the undisturbed sphere, and $a\,c\,b\,d$ a section of the body when rendered tidally prolate. The tidal elevation is expressed by $a\,m$ and the depression by $o\,c$. (2.) Where the tide-bearing body consists of a central part, $r\,t\,s\,u$, Figure 38, having a higher coefficient of viscosity than the surrounding part. Here the nucleus will yield in a less ratio than the envelope. The prolateness of the envelope, but for the influence of relative rotation, will be the same as if the whole body were of the same substance as the envelope, and the prolateness of the nucleus will be nearly the same as if the envelope were absent. The tidal fluctuations in the envelope are expressed as in the deformative tide; but the re-

sulting depth of the envelope over the tidally raised nucleus, will be the depth resulting in case of a rigid nucleus, diminished by the amount of the actual tide in the viscid nucleus. (3.) Where the tide-bearing body consists of a perfectly rigid nucleus, $r\,t\,s\,u$, Figure 39, and an envelope susceptible to tidal action. Here, also, the prolateness, disregarding rotation, becomes the same as if the whole body were of the matter forming the envelope. The dimensions of the tide in the envelope will be expressed as before; but the total depth, $a\,t$, of the envelope at high tide, will not be diminished by any tide in the nucleus; nor will its depth, $c\,r$, at low tide, be increased by any ebb in the nucleus. Though it is doubtful whether this case exists in nature, we have to deal with cases where the nucleus is more or less rigid, and the degree of rigidity is indicated by the difference between $a\,e$, Figure 38, the actually measured depth, and $a\,t$, the depth calculated on the hypothesis of a perfectly rigid nucleus. This difference shows the amount of tidal yielding in the nucleus. But even this operation, however desiderated, has not been satisfactorily accomplished in practice.

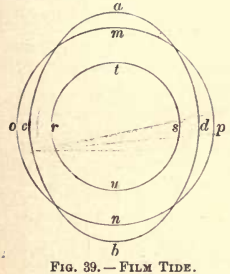

FIG. 39. — FILM TIDE.

The total vertical fluctuation of the tide is the sum of the flood and ebb tides; or in Figure 38, it is $a\,m + o\,c$. The flood tide rises twice as high above the mean sphere as the ebb tide falls below it. This is apparent from the general consideration that the deficiency of fluid causing the ebb is spread over a greater surface than the excess of fluid causing the two flood-tides. The one is spread over a broad zone encircling the ellipsoid, while each flood-tide

is spread over a circular area of about one-fourth the extent. Each circular area, nevertheless, is more than a quadrant in breadth, having a radius, in a homogeneous spheroid, of 54° 44′.

The tidal effect on the same tide-bearer, is directly as the mass of the tide-producer, and inversely as the cube of its distance. But for any other tide-bearer, the effect is also proportional to its radius.*

* These principles result from the following reasoning:

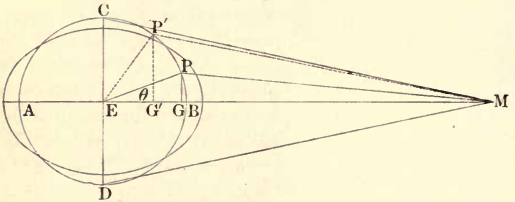

FIG. 40.—QUANTITATIVE RELATIONS OF TIDES.

Let D = E M (Figure 40) = distance between centres of tide-bearer and tide producer,

m = mass of tide-producer,

R = E B = radius of tide-bearer.

Then the attractions at B, E and A are expressed by

$$\frac{m}{(D-R)^2}, \quad \frac{m}{R^2} \text{ and } \frac{m}{(D+R)^2}.$$

Subtracting the second from the first, and the third from the second, we get, very nearly,

$$\frac{2\,m\,R}{D^3} = \text{Excess of attraction at B over E;}$$

$$\frac{2\,m\,R}{D^3} = \text{Excess of attraction at E over A.}$$

But the latter is actually a little less than the former.

These expressions show that the efficiency of the tidal force of the same tide-producer *varies directly as the radius of the tide-bearer and inversely as the cube of the distance of the tide-producer.*

Now, further, if we assume any point P, on the surface of the tide-bearer, at the angular distance ϕ from the line E M, joining the centres, and put g for intensity of gravity on tide-bearer, and ρ for the relative density of a thin external film covering a rigid nucleus, then the elevation (or depression) of P above the surface of the equivalent sphere, expressed in terms of radius (assumed as unity), will be

$$T = \frac{3\,m}{2\,D^3 g} \cdot \frac{1}{1-\frac{3}{5}\rho} \left(\cos^2\phi - \tfrac{1}{3}\right) \quad \text{(1)}$$

There is another cause of tidal protuberances in certain cases. Suppose two bodies in space having equal masses and densities revolve about the common centre of gravity between them. Now, each is in a position to create tidal effects on the other through the operation of gravitation, as just explained. But, in addition to this, the differential

This is a general expression for the height of any point of a film-tide having the relative density ρ (that of the nucleus being unity).

If the spheroid is homogeneous, that is, if $\rho = 1$,

$$T = \frac{3m}{2D^3g} \cdot \frac{5}{2}(\cos^2\phi - \tfrac{1}{3}). \quad - - - - - - - - - - - - (2)$$

If, in the homogeneous spheroid we take $\phi = 0°$ or $180°$, then $\cos^2\phi - \frac{1}{3} = \frac{2}{3}$, and

$$T' = \frac{5}{2} \cdot \frac{m}{D^3g} = \text{height of flood-tide}, \quad - - - - - - - - - (3)$$

If we take $\phi = 90°$ or $270°$, then $\cos^2\phi - \frac{1}{3} = -\frac{1}{3}$, and

$$T'' = -\frac{5}{4} \cdot \frac{m}{D^3g} = \text{depression of ebb tide.} \quad - - - \quad - - (4)$$

It may be added here that, in the case of the earth, $\rho = \frac{2}{11}$, and using this value,

$$T' = \frac{55}{49} \cdot \frac{m}{D^3g} = \text{theoretical mean flood-tide.} \quad - - - - - (5)$$

while

$$T'' = -\frac{55}{98} \cdot \frac{m}{D^3g} = \text{theoretical mean ebb-tide.} \quad - - - - (6)$$

To find at what angular distance from the zenith of the tide-producer the tide in a homogeneous spheroid is 0, we have the equation,

$$0 = \frac{3m}{2D^3g} \cdot \frac{5}{2}(\cos^2\phi - \tfrac{1}{3}),$$

in which as ϕ is the only variable quantity we must have $\cos^2\phi = \frac{1}{3}$, or $\cos\phi = \sqrt{\frac{1}{3}} = .57735 = \cos 54° 44'$. This arc then, is the radius of the spherical meniscus formed by the flood-tide or tidal protuberance.

To render the formula (1) more general, we must introduce the radius of the tide-bearer as a factor, and this gives

$$T = \frac{3mR}{2D^3g} \cdot \frac{1}{1 - \frac{3}{5}\rho}(\cos^2\phi - \tfrac{1}{3}). \quad - - - - - - - - - - (7)$$

If, in any other couple tidally connected, the quantities D, R. m, g have the values d, r, μ, g', the height of the tide will be

$$t = \frac{3\mu r}{2d^3g'} \cdot \frac{1}{1 - \frac{3}{5}\rho}(\cos^2\phi - \tfrac{1}{3}),$$

whence $\frac{t}{T} = \frac{\mu}{m} \cdot \frac{r}{R} \cdot \frac{D^3}{d^3} \cdot \frac{g}{g'}$. But if M and M′ be the masses of the two tide-bearers in these values of T and t, then $g' = g\frac{M'}{M} \cdot \frac{R^2}{r^2}$, and substituting,

$$t = T \cdot \frac{D^3}{d^3} \cdot \frac{R^2}{r^2} \cdot \frac{M}{M'} \cdot \frac{\mu}{m}.$$

This gives the height of the tide on one spheroid with one tide-producer in terms of the height of the tide on another spheroid with another tide-producer.

centrifugal tendency on the nearer and farther sides of each in respect to the common centre of gravity, will impart to the farther side a tendency to recede from the centre, and to the centre a tendency to recede from the nearer side. The result must be the same as when similar tendencies are produced by gravity. The body becomes a prolate spheroid. This prolateness becomes important where a body of considerable volume revolves with rapidity in an orbit comparatively small, as when a body of small mass and low density revolves rapidly about another of large mass. But in a couple like the earth and moon where the centre of gravity lies so near the centre of the larger body,* this cause would hardly produce a perceptible prolateness of the larger body. In aëriform masses of matter, however, where the volume is generally great, and cohesion of parts a minimum, we might expect this cause to become quite preceptibly operative. A tidal deformation produced by this cause alone would tend to transfer the heavier parts of the body to the remoter side, and leave the lighter upon the nearer side. But this action could only coexist with proper tidal action, which alone would create a tendency in the heavier parts to pass to the nearer side, leaving the lighter to occupy the remoter side. The circumstances under which one of these tendencies would prevail over the other in a body (like our moon) turning always the same side toward the tide-raising body (like the earth) have been heretofore discussed. [Part I, Chap. ii, § 4, 3, (2).] If the rotary and orbital motions are not synchronous, the effect of tidal action upon the distribution of heavier and lighter parts must be nullified.

2. *General Effects of Tidal Action in Planetary Life.* Heretofore in discussing the vicissitudes of nebular masses disengaged from primitive nebulæ by a process of annula-

* The centre of gravity between the earth and moon is only 2,963 miles from the earth's centre.

tion, I have had occasion to direct attention, in a general way, to the effects of tidal action both as resulting directly from attractions and also from differential centrifugal tendencies. In the early history of planetary bodies tidal actions acquire a remarkable degree of importance. I desire, therefore, in entering on a recital of the events of primitive planetary history, to explain preliminarily, the general mode of reaction of tidal masses. I refer here to actions resulting from the existence of tides.

I have stated that all bodies are susceptible of some degree of tidal deformation. The character of the tidal effect depends, under a given tidal action, on the *facility* with which the parts tidally moved change their relative positions, and, upon a rotating spheroid, the *promptness* with which they respond to the tidal solicitation. These conditions concern the *height* of the tide and its *position* in reference to the tide-producing body. In a perfect fluid the height of the tide will be determined only by the general law of sphericity; and the apex of the tide will be on the shortest line joining the centres of gravity of the two bodies. In matter possessed of any degree of viscosity, the height of the tide will be less than in a perfect fluid, and the position of the tide will be somewhat ahead of the zenith position of the tide-producing body Viewed in reference to time of culmination of the tide-producer, the tide therefore lags *behind*. In a system, like our solar system, where the prevailing motions are from west to east, the crest of the tide will be to the east of the zenith position of the tide-producing body. In other words, to an observer at the apex of the tide, the tide-producing body will have passed the zenith. Thus, if O and C be the centres of the two bodies concerned, and the body O is rotating in the direction of the arrow, then the apex of the tide, B, will have passed the point A, under the zenith of the tide-producing body C, and will be to the east of

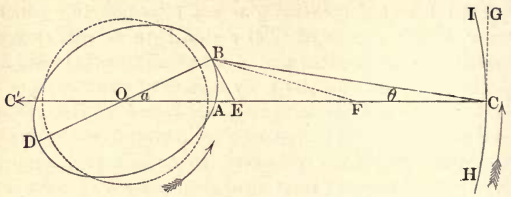

FIG. 41.—ILLUSTRATING A LAGGING TIDE.

A by the angular distance B O A. This circumstance, due to the viscosity of the body O, gives rise to some very interesting deductions. These I will now endeavor to make plain.

(1.) *The lagging of the tide tends to a retardation of the rotary motion of the tide-bearing body.* — A simple inspection of the figure suffices to show that the attraction of C upon the tidal protuberance at B must tend to draw B around toward A. It is true that attraction is exerted similarly by C upon the tidal protuberance at D; but the influence exerted upon the centre is greater, and the effect of this is a relative movement of D backward. To make this plainer we may conceive the anti-tide caused by an attraction from the opposite direction, C' O; then it is evident that the tangential component of this attraction, exerted at D, will tend to rotate the spheroid in a direction contrary to the arrow. But as B and D are constrained to the surface of the spheroid, the tendency of those two points is to bring the prolate axis B D into coincidence with the line C' C, passing through the centres of gravity of the tide-bearer and tide-producer, that is, the lagging of the tide results in a force which opposes the rotation of the body O.*

* The horizontal component of the attraction which tends to move B toward A may be represented by the tangent B E, Figure 41. Then by the principle of the parallelogram of forces we may readily deduce a rough general expression

This cause of retardation must be set down as real, and in the actual constitution of matter, as universal as the existence of tides. But now the viscosity of matter comes into action in another way. The tide-bearer not being rigid, the retarding effect is not fully experienced. The protuberant mass at B tends to *slide over* the bodily mass, and to undergo a translation toward A. The amount of actual translation will be inversely as the coefficient of viscosity. In a highly viscous mass the motion of translation will be but slight, and the protuberance will yield only as it can draw the whole body around with it, or a little more than this. In a highly fluid mass the protuberance will yield more readily, the translatory movement will be greater for the same lagging, but, on the other hand, the lagging will be less, and the horizontal component of the tidal force will be diminished also.

In the case where the tide-bearer is internally more rigid than near the surface, or has parts more rigid, against which the translated tidal swell may strike, the retarding influence assumes more characteristically the nature of frictional action. This action must exist whenever any of the moving parts yield more readily than other parts in juxtaposition with them. Retardation through frictional action presents the most intelligible

for this component. For, in all cases where the angle $BOA=\alpha$ is small, the distance AE is relatively inconsiderable, and CE may be taken as the distance of the tide-producer from the surface of the tide-bearer, and OB may be taken as the mean radius of the latter. Then, if $\theta=BCE$, the angle at the tide-producer subtended by the tangent BE, we shall have in the triangle BOC,

$$\sin\theta=\sin\alpha\,\frac{BO}{BC}.$$

Also, in the triangle CBE,

$$BE:BC::\sin\theta:\sin BEC=\sin(90^\circ+\alpha)=\cos\alpha,$$

$$\therefore BE=BC\,\frac{\sin\theta}{\cos\alpha}.$$

In this expression BC represents the whole attraction upon B, and BE, its horizontal component, or the value of the force acting against the rotation of the tide-producer. Putting F for the former and substituting the value of $\sin\theta$.

$$BE=F\,\frac{BO}{BC}\tan\alpha.$$

case where a film like the ocean covers a nucleus relatively solid which rises above the surface of the film in certain regions, presenting shallows and fixed resistances to the tidal movements of the film. The mere vertical rise and fall of the tides will, in such case, establish currents, the initial impulse of which is toward the crest of the tide from both directions, but which, from the configuration of the solid resistances, may be deflected in any assignable direction. While these currents must exert important erosive agency, it is not these which develop the friction that tends to retard the rotation of the tide-bearer. These currents may, indeed, act in all directions. It is the translatory movement of the tide which determines a balance of action in the direction of the translation; that is, in our system, toward the west. Thus, the eastern borders of the resistances should receive somewhat severer action than the western. While, however, all these actions and movements are real, they are very minute, and can only become of cosmical importance when their results accumulate through secular periods.

In consequence of the retral translation of the tidal mass, its position will not be accurately at B, the point determined by the viscosity of the tide-bearer, but at some point between B and A. The actual tide will occur, therefore, a little sooner than might be calculated on the basis of viscosity alone. There ought to be thus a slight *anticipation* of the tide.

One point more. The apex of the tidal swell, but for the lagging here under consideration, would be exactly beneath the tide-producer. But, in consequence of the lagging, the tidal apex is developed some distance to the east of the zenith. The point which had been beneath the zenith has been carried around by the rotation of the tide-bearer. It has been carried around on the equator or a parallel of latitude. For the present explanation let us

suppose the tidal crest to lie under the equator. The tide-producer acts upon the protuberant mass from a position a little further west. There are two reasons now why the greatest translatory effect should be produced at the apex on the equator. *First*, that part of the tidal swell is nearer the tide-producing body; *second*, the apex being more elevated than the portions lying to the north and south, must be more susceptible to the attraction exerted upon it. The tidal action is more transverse, and the horizontal component is greater. The consequence is that the apical portion of the tidal swell must recede westward more than the portions to the north and south. If, therefore, the meridian passing over the apex of the tidal swell at any moment could be fixed to the receding surface, it would be broken at the equator into two curves inclined to the meridian, and presenting their convexities toward the east. The equatorial portion would be borne westward more than the other portions. This curious and interesting result, first made known by Mr. G. H. Darwin, will be hereafter applied to the case of the earth.

In Figure 42 I have attempted to illustrate more fully the consequences of a lagging tide, as far as explained, and also other consequences remaining to be noticed. Here we have a perspective view of a planetary spheroid or tide-bearer, having its axis N S inclined to the plane of the orbit O M, in which is moving a moon or tide-producer. The direction of the axial and orbital movements is shown by the arrows. The broken and dotted lines in the view of the planet represent parts on the invisible hemisphere. N S is the axis of rotation; E E E E is the equator; L L L L is the great circle of intersection of the plane of the orbit O M with the surface of the planet. It cuts the equator at two opposite points, X, X. C C C C is a parallel or small circle tangent to the last mentioned at *m*. Other small circles are drawn, and also several meridians, for the

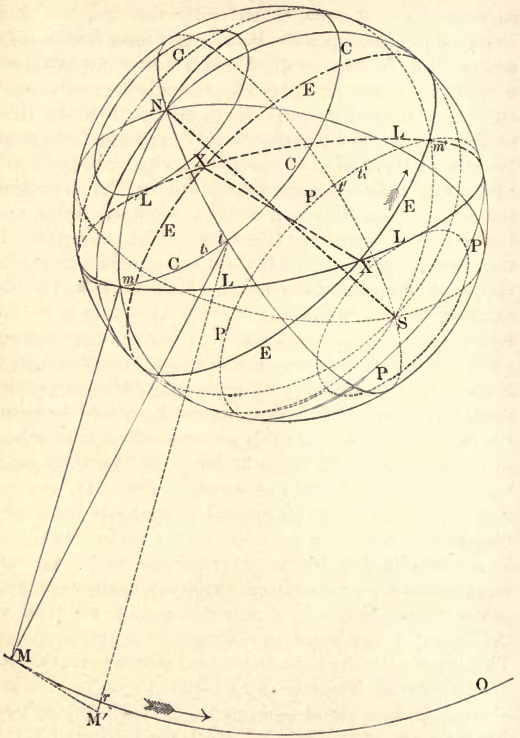

FIGURE 42.—ILLUSTRATING THE SECULAR EFFECTS OF TIDES IN A ROTATING VISCOUS SPHEROID.

N and S are the poles of the spheroid.

EEEE, the equator.

CCCC, a small circle, in north latitude, parallel with the equator and tangent to LLLL at *m*.

PPPP, a small circle, in south latitude, parallel with the equator and tangent to LLLL at *m'*.

purpose of giving intelligibility to the diagram. We are under the necessity of placing the tide-producer M, disproportionately near the tide-bearer; but this only exaggerates the quantities which it is desired to bring into notice, and hence is a real help.

Now the tide-producer is supposed to be in the zenith over m, and accordingly a tidal effect is progressing at m. But this effect, in consequence of viscosity, does not reach its culmination until the rotation of the planet has transferred the point m to t, and t, therefore, is the place of high tide. Suppose M to be the tide-producing body at this juncture. Then a tidal protuberance exists on the meridian passing through t, somewhat to the east of the zenith position of M, and the attraction of M exerted upon t tends to rotate the planet backward, around the axis N S, toward m. The amount of this tendency is the retarding effect of the lagging tide. The apex of the anti-tide is at t' instead of m', and the lagging of the anti-tide brings it to a position where the attraction of the theoretical anti-tide-producer tends to draw it retrally from t' toward m', and thus as before, to retard the rotational motion of the planet.

The attraction of the tide-producer exerted upon t produces a virtual retral motion which we may assume represented by $t\,t_1$. The distance $t\,t_1$, is therefore the anticipation

L L L L, intersection with the spheroid's surface of the plane of the orbit of the tide-producer.

X X, diameter joining intersections of equator and L L L L.

M, tide-producer, assumed to be vertically over m.

O M, portion of the orbit of the tide-producer.

m, point under M, and the apex of the tide in case of perfect fluidity.

t, apex of the tide as determined by lagging from m to t.

t_1, actual apex of the tide, as resulting from lagging and from retral slipping from t to t_1.

m', t', t_1', corresponding points of the anti-tide.

M r, acceleration of the tide-producer caused by the attraction of the tide from t, or more exactly from t_1.

M' r, recession of the tide-producer caused by its acceleration and increased centrifugal tendency,

of the tide, or the amount by which it occurs *sooner* than might be expected when the calculation of its position is based simply on the amount of lagging due to the viscosity. It will be borne in mind that the retral pull may be conceived as developing in part an actual retardation of the planetary spheroid, and in part a retral translation of a portion of the more fluid film upon the surface. The relative amounts of retardation of the whole body, and retardation or retral translation of the surface, will be determined by the viscosity of the film and its opportunities for action against fixed or relatively fixed parts of the included nucleus.

Supposing a film more fluid than the nucleus, and a tide-producer M, acting on a tidal swell whose crest is at t, then obviously, the greatest amount of retral movement will be produced at t, while north and south of t the retral movement will be less, both because of the greater distance of the attracting body and of the less height of the tide.

As the tide-producer moves in its orbit it reaches a point directly over the node X. In this position the retarding factor of the attraction is more effective than before, and the linear retral motion of the surface-film will be greater, since the retarding force is applied at a greater distance from the axis. When, at a subsequent epoch, the tide-producer is over m', and the tide is at t', then the retarding and translatory effects become precisely as at m and t. Hence the retarding and translatory effects attain a maximum when the tide-producer is nearly over the planetary equator, and diminish thence during the northern and southern declinations. That is to say, considering the aggregate translatory effects during an orbital revolution of the tide-producer, the retral movement will be greatest at the equator and will diminish thence toward the poles. The equatorial regions will suffer a greater westward shift-

ing of longitude than regions farther north and south; so that lines once meridional will eventually present an inclined double convexity eastward, with north-eastward trends north of the equator, and south-eastward trends south of the equator.

As the lagging of the tide results from the viscosity of the tidally disturbed matter, the amount of the lagging becomes a measure of the viscosity. But, that it may be accurately such measure, correction must be made for the retral slipping of the superficial film in the latitude where the apex of the tide is situated.

In the case of a tide-bearer constituted of a nucleus of higher viscosity, and an enveloping film of lower, each part will develop its own tidal protuberance, and that of the nucleus will lag more than that of the film. This is shown in the adjacent figure, where A B is the prolate

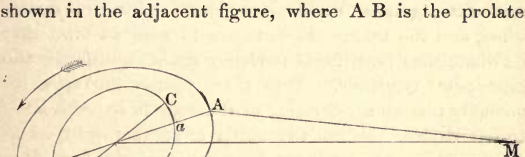

FIG. 43.—DISCORDANT TIDES OF NUCLEUS AND FILM.

axis of the film, and C D the prolate axis of the nucleus. It is to be remarked, in view of this state of things, that the problem of the rigidity of the nucleus as depending on the measured depth of the tide A a, must take account of the fact that a is not the point at which the nuclear tide is developed.

(2.) *The lagging of the tide produces a slow recession of the tide-producing body.*—Recurring to Figure 41, let H I represent a portion of the orbit of a tide-producer

moving in the direction of the arrow. This, according to the process of world-making which we here maintain, will be in the same direction as the rotation of the tide-bearer. The apex of the tide will be, therefore, at B, in advance of the position of the tide-producer, and an attraction will be exerted by the tidal mass upon C, in the direction C B. While the greater part of this attraction coincides with the mean centripetal force drawing C toward O, a small component of it, as the diagram shows, tends to accelerate the motion of C in the direction C I. But C was supposed to be moving with such orbital velocity as held it balanced between centripetal and centrifugal forces, and if now that velocity is increased, the centrifugal tendency is increased, and C tends to move in the direction of the tangent C G. That is, its distance from O is increased. But now, removed to a greater distance, the centripetal force is diminished, and the tide-producer moves in such an orbit that its diminished centrifugal tendency again equilibrates the centripetal tendency. Thus there results the apparent anomaly that an acceleration of the body in its orbit leads to retardation. To put the matter in another light, let us consider that while the total attraction of the body O is the same with or without the tide, one part of it when the tide exists, is exerted in the direction C B instead of C O, and develops the tangential tendency C G; while the remaining part exerted in the direction C O is less than the centripetal force exerted by the body when not tidally distorted. That is, the proper centripetal force is diminished. But since the orbital velocity of C is the resultant of centrifugal and centripetal components, it will be diminished by the diminution of the centripetal component. Diminution of orbital velocity diminishes in turn the centrifugal tendency. So the body C, in being drawn along the tangent C G, and getting a little outside of its orbit, experiences diminution of centripetal force, orbital velocity and

centrifugal force. In other words, it revolves at a slightly greater distance from the centre O, and with a diminished linear and angular velocity.* The principle is precisely the converse of that under which a resisting medium, in opposing the orbital motion of a body, determines an acceleration of velocity, and motion in a smaller orbit.

This reaction of the tide may perhaps be more thoroughly understood by the use of the general diagram, Figure 42. Here as before, the crest of the tide is at t_1 when the tide-producer is in the zenith at m, and the action exerted from t_1 tends to accelerate M in the direction of r; but acceleration causes M to depart from its orbit in the direction of the tangent M M′, and thus, as before, orbital retardation is the ulterior result. The same action takes place at whatever point along the great circle L L L L the tide may exist during the movement of M forward in its orbit.

A very high state of viscosity may result in retardation instead of acceleration of the tide-producer in its orbit. Let the annexed diagram be a projection on the plane of the planet's equator. Then when the lagging of the tide amounts to 90°, as at t_1, the anti-tide at t'_1 exerts an attraction on M which nearly neutralizes the attraction of the tide. At some distance east of t_1, as at t_2, the attraction exerted upon M by the anti-tide, t'_2, exceeds the attraction exerted by the tide. The excess of action of the anti-tide results in a retardation of M; it is, therefore, drawn by centripetal action nearer to the planet, and its velocity is accelerated. A very high state of viscosity

*This case illustrates the interesting fact that the influence exerted by an attracting body must depend, in certain positions, upon its figure. If there were no lagging of the tide the motion of the tide-producer would not be affected; and if the lagging were just 90°, the influence of the anti-tide would neutralize that of the tide. So the equatorial protuberance of an *oblate* spheroid must exert an influence on the motion of a body revolving around it, except when the body is in the plane of the protuberance, or exactly in the line of the axis produced—a relation which never exists in our system.

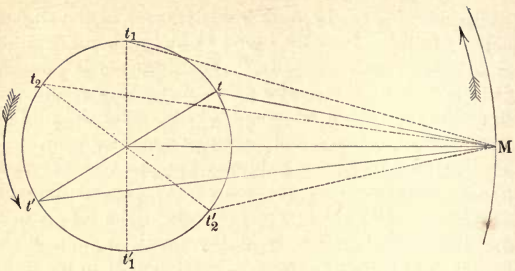

FIG. 44.—VARYING REACTION RESULTING FROM VARYING VISCOSITY.

exists at the surfaces of planetary bodies when passing from the fluid to the solid state, but whether it ever produces sufficient tidal lagging to work a retardation of a satellite is unknown. Undoubtedly the more prolonged and older fluidic condition, accompanied by accelerative lagging of tide, impresses more important results on the life-history of satellites.

This direct retardative result proceeds from the influence of excessive viscosity in any state of inclination of the orbit and the planetary equator. The result will be reached also, with a lower degree of viscosity, in proportion as this inclination is increased; because the greater the inclination the sooner the lagging tide is carried by the planet's rotation around to a point in the rear of the radius vector of the tide-producer. This will be understood from the general diagram, Figure 42, by conceiving the great circle L L L L to have such obliquity as to be tangent to the small circles around the poles N and S. A tide inaugurated at any point on this great circle will be carried nearly at right angles away from it by the planet's rotation, and the tidal culmination may be reached, especially if the lagging is great, at such a distance that the curvature of the parallel brings the crest of the tide to

the west of the radius vector of the tide-producer. It appears, therefore, that as the inclination increases, the degree of viscosity which will produce retardation diminishes, and when the inclination is 90°, acceleration results under all degrees of viscosity, when the tidal crest is in the southern hemisphere, while retardation results when it is in the northern hemisphere. On the contrary, as the inclination diminishes, the degree of viscosity requisite to produce retardation increases, and when the inclination is zero, the viscosity must be such as to produce a lagging of more than 90° of longitude.

(3.) *The lagging of the tide increases the inclination of the equator of the tide-bearer to the orbit of the tide-producer.*—By reference to the general diagram, Figure 42, it is seen that an attraction exerted by a body M upon a tidal protuberance at t_1 imparts not only a tendency of the tide-bearer to rotate backward around the axis N S, but also a tendency to rotate around the axis X X. In other words, the actual motion of the tide-bearer in the direction of the pull may be resolved into two rotations about the two axes named. The tide-producer is always vertically over some point of the great circle L L L L. When that point is north of the equator, the rotation of the tide-bearer carries the tide north of the plane L L L L, and an attraction exerted from that plane must tend to bring the tidal crest into the plane; that is, to bring a point north of the plane L L L L southward into that plane. The effect of this must be to increase the inclination of the axis N S toward the axis of the plane L L L L. When the apex of the tide is south of the equator, the rotation of the tide-bearer carries it south of the plane L L L L, and an attraction exerted from that plane must tend to bring the tidal crest into the plane; that is, to bring a point south of the plane L L L L northward into that plane. The effect of this must also tilt the axis of

the tide-bearer into a larger inclination to the axis of L L L L. In all positions of its orbit, therefore, the tide-producer increases the angle formed by the great circles E E E E and L L L L.

Reciprocally, however, the reaction of the tide in all positions where the inclination referred to is increased, exerts a tendency to move the tide-producer M above or below the plane of its orbit. When the tidal crest by lagging is carried above that plane, the tide-producer is drawn above it. In all that half of its orbit which lies north of the equator, the tendency of the lagging tide is to keep the tide-producer above the plane of its orbit. In all that half of its orbit which lies south of the equator, the tendency of the lagging tide is to keep the tide-producer below the plane of its orbit. That is, one-half of the orbit is elevated and the other is depressed. The inclination of the orbit is changed in reference to a constant plane; say the fundamental plane of the planetary system.

The action of the tide in increasing the angle between the axis N S and the axis of L L L L would not result in a steady movement of one pole from the other. The pole N would pursue a sinuous course, making one sweep to the east and one to the west at each semi-revolution of the tide-producing body. Similarly the path of this body would be sinuous — moved twice above its mean position and twice below it during each revolution.

As the viscosity of the tide-bearing medium increases, the position of t in Figure 42 moves around farther east on the parallel C C C C. At length, with further supposable increase of viscosity, the amount of lagging becomes 90°. At this point the increase of obliquity ceases. Beyond this point, the effect of lagging is to diminish the obliquity. This is more clearly shown, for a particular position of the tide-producer, in the annexed diagram,

Figure 45, where the equator and parallels and plane of the orbit of the tide-producer (m A) are seen, from an infinite distance, projected in straight lines. M is the projection of the tide-producer. When the projection of the retardation is $m\,t$, the effect of attraction toward the plane of the orbit m A, is to increase the inclination of the axis N S. When the projection of the retardation is mt_1, no effect is produced. When the projection of the retardation is mt_2 or mt_3, the effect of attraction toward the plane m A is to diminish the inclination. The theoretical anti-tide-producer acts concurrently, as shown in this diagram. It appears, therefore, that with a high state of viscosity the increase in the obliquity may become *nil*, or even changed to a diminution.

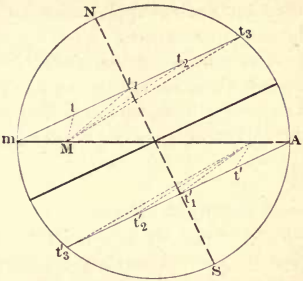

FIG. 45.—TIDAL INCREASE AND DIMINUTION OF OBLIQUITY.

The three classes of tidal reactions thus explained are reciprocal. The planetary body exerts a tidal influence upon the lunar body as much greater than that experienced itself, as its mass is greater than that of the lunar body; though the height of the tide raised depends also on the radius of the lunar body, and the mobility of its parts. Since the lunar body must be viewed as always more or less viscous, and on our theory, must at some stage pass through a semi-fluid state, the lagging of the tide borne by this body must tend always to retard its rotary motion. This general deduction leads us to some

very interesting applications to particular cases, as will hereafter be shown.

The reaction of the lunar tide upon the orbital motion of the planet around the common centre of gravity of the two bodies, however insignificant in amount, is a sequence which is real. Let M, Figure 46, represent a moon, a the

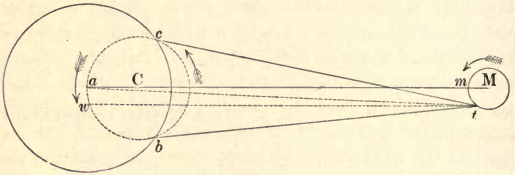

FIG. 46.—THE TIDE-BEARER VIEWED AS TIDE-PRODUCER.

centre of gravity of a planet, and C the centre of gravity between the moon and the planet. The centre of gravity a revolves about the centre of gravity C in an orbit $a\ b\ c$. On the moon the lagging of the tide brings its apex to t, and this lagging tide acts on the centre of gravity a. As this action is not in the direction of the radius vector a C, the tendency is to accelerate a toward w. This, as before, by increasing the centrifugal force increases the distance from C to a, and ends in retardation of a in its orbit. As the planet and satellite are always in the same position in relation to C, this action exists in all parts of their respective orbits. So the tidal retardation of the lunar-planetary revolution about the common centre C is the sum of the reactions from the lagging tides upon the two bodies.

It will be noticed also, that with a high degree of viscosity, producing a lagging of more than 90°, the reaction upon a exerted by the anti-tide of the satellite will exert a retarding influence upon the orbital motion of a. The ac-

celerative and retardative influences of planet and satellite are, therefore, precisely reciprocal and consentaneous.

Similarly, it will appear, on a moment's consideration, that if the axis of the satellite possesses some degree of inclination to the axis of the planet's orbit, such inclination will be increased and diminished under the same conditions as increase and diminution of the planet's inclination to the satellite's orbit.

This whole subject ought to be contemplated under relations still more general. Each of the planets stands in the tidal relation of a satellite to the sun, and the sun is a tide-producing body to each of its planets. The remoteness of the major planets diminishes this reciprocal action, perhaps, below the limit of cosmical importance, but, on the contrary, tidal actions within nearer limits must possess a high degree of importance. The same kind of influence which a planet exerts upon a satellite, the sun exerts upon the planet itself. That is, the solar tide tends to retard the planetary rotation, to retard its angular motion in its orbit, and to increase the inclination of its axis to the axis of its orbit. The tide upon the sun must tend also to draw the planet out of the plane of its orbit, and thus to increase the obliquity of that plane to the plane of the sun's equator.

We are thus brought face to face with the striking fact that tidal evolution is a suggestive explanation of many of those apparent anomalies which have been cited as difficulties in the nebular theory. Inadequate rotary and orbital velocities may be thus explained. Inclinations of axes of rotation may have been brought to a higher degree — and highest upon those planets most affected by solar tides. Even the inclinations of the planetary orbits may have been increased by tidal protuberances on a sun rotating with some preëxisting inclination of its axis. We cannot, however, explain all axial and orbital obliquity in this way.

Change in obliquity depends on the antecedent existence of some obliquity. With obliquity *nil* we have conditions of equilibrium. There must have been other causes to inaugurate the obliquity which tidal influence increases. The existence of other causes has been heretofore pointed out. (Part II, ch. i, §§ 2–3.)

3. *Tendency to Synchronism of Rotary and Orbital Motions.*—We may now proceed to trace more specifically some necessary deductions from the physical principles thus defined. Every planetary body in the solar system has always been tidally influenced by every other body in the system. We may disregard, however, at present, the tidal disturbances excited in the sun, and also the influences of the primary planets upon each other. Great importance, however, must be conceded to three classes of tides: *First*, The influence of primaries upon their secondaries. *Second*, The influence of secondaries upon their primaries. *Third*, The influence of the sun upon the planets. The greatest tidal distortion would result from the influence of a primary of large mass upon its own satellites. The mass of Jupiter being three hundred times that of the earth, and his inner satellite being but little more remote than our moon from the earth, the tidal influence of Jupiter upon his inner satellite should be, for these reasons, about three hundred times as great as the influence of the earth upon the moon. But since this satellite has about the diameter of the moon, with less than half its mass, the tidal influence of Jupiter would become still more enormous. The tidal influence of the earth upon the moon, so far as due to relative mass, should be about eighty times as great as that of the moon upon the earth. The enormous tides raised upon the satellites while in a primitive aëriform, fluid or semi-fluid condition must have exerted a most important influence upon their development. Confining our attention to the retarding

effect, this must have had almost a controlling power over their axial rotations. It may even be doubted whether the whole process of shrinkage after the attainment of a semi-fluid state, and the consequent diminished tendency to accelerated rotation, has been sufficient to overcome the tidal influence of the primary in any single instance, so as to establish for any epoch an angular motion more rapid than the satellite's orbital motion. As the moon turns always the same side toward the earth, it is reasonable to infer that this condition has been produced by the tidal influence exerted chiefly by the earth. It seems probable, also, that the condition was assumed at an early period in the moon's history, even if a non-synchronous rotation had once been established during an earlier aëriform period when freer mobility of parts gave the moon somewhat the character of a perfect fluid, in which tidal lagging would not take place. So far as we can judge from observation, other satellites have attained a similar state of synchronistic motions; and this is certainly in accordance with our reasoning.

A reciprocal though greatly inferior influence is exerted, or has been exerted, by each satellite upon its primary. During the plastic condition of the primary, the deformative tide must lag, and a retarding effect must result. Each planet has been strained to desist from its rapid rotation, and present constantly the same side toward its most powerful satellite. Without the least doubt this influence, continued through millions of years, has materially retarded the rotary motions of the planets.* Those

*Kant, the great thinker, whose sagacity can scarcely be too much respected, was the first to make note of these reciprocal tidal actions on the earth and moon. See his prize essay, presented in 1754 to the Berlin Academy of Sciences, entitled: *Untersuchung der Frage, ob die Erde in ihrer Umdrehung um die Achse, wodurch sie die Abwechselung des Tages und der Nacht hervorbringt, einige Veränderung seit den ersten Zeiten ihres Ursprunges erlitten habe, und woraus man sich ihrer versichern könne.*

planets would be most retarded whose masses sustain lowest relations to the masses of their satellites — allowance being made also for distances. The earth, and possibly Mars, should have departed most from their primitive axial velocities; Jupiter and the exterior planets least. But Venus and Mercury being unprovided with satellites, have been unaffected by their influence. Observation has not certainly shown what is their actual rate of rotation.

The tidal influence exerted by the satellites upon the planets would be reinforced by the sun's influence upon them. At the distance of the earth, the solar tidal efficiency is two-fifths that of the moon upon the earth. At the distance of Venus the solar tidal efficiency is one and two-fifths times as great as at the earth; which gives at Venus a solar tide two-thirds as great as the lunar tide upon the earth. At Mercury the solar tidal efficiency is 17.44 times as great as upon the earth, which is 6.976 times as great as our lunar tide. These two planets, therefore, while exempt from the retarding influence of satellites, have suffered very important retarding influences exerted by the sun. It would not be a stretch of probability to conclude that Mercury, at least, has attained already a state of synchronistic axial and orbital motions, even if such state has not existed from the gaseous epoch of the planet's evolution.

At a later period in a planet's career, after approximate rigidity has diminished greatly the retarding influence of deformative tides, the tidal disturbance of the fluids on their surfaces maintains a frictional retardative action which continues the tendency to synchronistic motions. Whenever a planetary surface becomes covered with a film of water, interrupted in places by protruding portions of the solid nucleus, then all tidal movements of the water along the shores of islands and continents, and over bottoms not beneath the influence of such dis-

turbances, is met by resistances which tend to destroy the motions. As the resultant of all the tidal motions is toward the west, the rotary motion of the tide-bearer is continually diminished, and continually approaches synchronism with the orbital motion of the tide-producer. Thus the earth is tending to settle into such a rate of rotation that one side will always be turned toward the moon. After this condition shall have been reached, the solar tide will further retard its rotation toward the limit where the same side will be turned constantly toward the sun. Meantime, however, after a planet's rotation, by this influence, becomes *slower* than the orbital revolution of its satellite, a lunar tide will spring up again, lagging behind the satellite, and tending to *accelerate* the planet's rotation. If the lunar tide should now retain all its former magnitude, the satellite would prevail over the sun, and prevent final synchronism with the sun. But the satellite, as has been explained, has receded from its planet, and its tide has diminished as the cube of the distance increased. Besides, the amount of lagging now is less, since the satellite passes the planet's meridians more slowly. Thus the power of the satellite may not be able to cope with that of the sun, and the planet may ultimately turn the same side continually toward the sun.

Whenever a body is brought to turn the same side constantly toward a tide-producer, then some important changes must take place in the distribution of the fluids upon its surface. Not only will a state of permanent bodily deformation result, and thus all mechanical development of internal heat be arrested, but now all the fluids will dispose themselves on the remoter side of the body. Thus all the water would be displaced from the nearer pole of the prolate axis, and accumulated about the remoter one. The atmosphere would also be similarly distributed. No body thus fixed in its position should

therefore present any seas, or perhaps atmosphere, to the view of an observer placed on the tide-producer which controls its rotation. This supposes, however, that these fluids exist in nearly the same proportion to the body as on the earth. But we shall discover hereafter another cause of the disappearance of water and atmosphere.

4. *Predetermination of Sub-meridional Trends.*—In the early incrustive periods of a planet's existence, the tidal disturbance would determine some permanent features of the surface. It seems to me that some meridional disposition of the structure of the crust would arise without the intervention of the retral translatory motion already considered in its general features. The tidal wave would be an immense swell of the liquid portion stretching meridionally from high northern to high southern latitudes. It would indeed, have a corresponding breadth from east to west. Its progressive changes of position, however, would be across the meridians. The successiveness of similar tidal conditions and effects would extend from east to west. This would be true of parallels north and south of the zenith positions of the tide-producing body, as well as of those experiencing the maximum tidal influence. Simultaneousness of tidal conditions and effects would extend meridionally. The progressive westward changes in the position of the swell must determine arrangements of the rising and sinking fragments having relation to the direction of the progress. Parts along the same meridian would sustain identical relations to the direction of the progress, and receive an identical and simultaneous impress. Though the next meridian would be immediately visited by the same action, it would be the simultaneous results rather than the successive ones, which would determine zones of homogeneous structure or similar condition, like the lines of growth over the surface of a sea-shell. Accessory causes would be joined to these influ-

ences. Whatever effects might result from the conjunction of any casual influences with tidal action, would arise simultaneously along meridional lines more or less extended.* Such casual influences might originate in storms or special conditions of the crust. It is reasonable to suppose, therefore, that the tides would impress some characteristics of surface meridionally disposed.

But there is a stronger reason for supposing this, as has been shown. The inertia of the tidal mass and the friction of moving parts upon each other would cause the summit of the swell to linger somewhat behind the meridian passage of the tide-producing body. This body would therefore exert constantly some force of displacement tending to give the tidal mass a slight motion of translation opposite to the direction of the rotation of the tide-bearing body. Whatever translatory motion of the tide wave might result — whatever pressure might be exerted by a tendency toward translatory motion, would be an effect which, combining with the casual influences, would still more distinctly impress meridional features upon the constitution and structure of the solidifying crust. The tendency to translatory motion may be very slight; the aggregate impression of all these causes may be slight; but if these are real physical causes they may aggregate enough to turn a balance of conditions, and leave on the surface of the solidified planet some record of their existence.

In the early incrustive stages this tide would not only break the forming crust into a mass of angular and afterward rounded fragments, but would initiate some tendency to westward motion for certain distances. When

*Transmeridional features might indeed be created by any influence changing its point of application in the direction of the tidal motion, as we find upon the exterior of a sea-shell lines of structure transverse to the lines of growth, and sustaining relations to causes which move in the direction of the growth.

this tendency should be finally overcome by aggregated resistances, the fragments would be left in long ranges meridionally disposed, which, though incomparably less pronounced, might be compared to the windrows of ice-blocks piled along the shore by the swell upon the surface of one of the great lakes. Thus a certain predisposition to meridional trends would be induced.

At a later stage, when a continuous floe-like crust should have come into existence, the same tidal swell would raise the crust in broad billows which would continually change their position westward on new belts of crust. Whatever action should be exerted — whatever effects produced, they would range meridionally, and this effect would be reinforced by the tangential component of the tidal action. Thus the crust would come into existence with ingrained meridional features in its structure, and with predetermined aptitudes to assume new features having the same general trend. If, subsequently, any cause should necessitate the development of wrinkles in the crust, the earliest ones must naturally assume meridional trends. Such trends once inaugurated, others parallel with them would, by a double necessity, come into existence if the wrinkling process should continue. Thus all the *primitive* wrinkles should, under a general law, exhibit trends across the parallels. At later periods, after an advanced differentiation of the planetary surface, secondary causes might induce wrinkles and folds of the crust trending in other directions. Great interest arises in the application of these principles to the case of the earth.

In these statements concerning the inauguration of meridional trends I have said nothing concerning the differential retrograde slipping of the equatorial regions and those situated to the north and south of the equator. It will be borne in mind, however, that the tangential component of the tidal force is most effective at the crest of

the tide. It follows, therefore, that the structural features thus far referred to as meridional would tend to assume, north of the equator, a trend somewhat northeasterly, and south of the equator a trend somewhat southeasterly.*

5. *Outflow of Molten Matter.*—The tidal elevation and depression of the planetary crust would not only cause extensive fractures, but would furnish occasion for the outflow of molten matter through the vents. It is certain that the effort of the underlying liquid to rise higher than the partially rigid crust would rise, would cause the fluid to escape through any fractures which might exist, and overflow the surrounding surface. This fluid solidifying around the border, would eventually build up a crater-like elevation of any assignable magnitude. In later periods, upon a planet supplied with the conditions of extensive denudation, these crateriform eminences might disappear; while on a planet not supplied with the conditions of denudation, they might remain indefinitely. These principles have a very important application in the case of the moon.

6. *Crushing Effects of Tidal Deformation.*—Planetary tides would never cease to be felt. A planet would never become so solid as not to yield to an influence as powerful, for instance, as that which the moon exerts upon the earth. The tide would be a perpetually shifting deformation of the solid parts of the planet. This must necessarily be accompanied by extensive molecular dis-

* Although the establishment of primitive meridional trends was worked out by me independently, I am indebted to Mr. G. H. Darwin for the suggestion that these trends would make an angle with the meridian. See his highly interesting memoir on *Problems Connected with the Tides of a Viscous Spheroid*, read before the Royal Society of London, December 19, 1878. Phil. Trans., Pt. II, 1879. Mr. Darwin shows that each point of the planet's surface moves from east to west with a linear velocity proportional to the cube of the distance from the axis, and the parts north of the equator change their longitude *from west to east* relatively to the equator, at a rate proportional to the square of the sine of the latitude.

placement. It is, in effect, a crushing agency, and the consequence must be the development of an enormous amount of heat. It would appear, therefore, that even after a planet should have been chilled to its centre, tidal deformation must continue to produce the phenomena of internal heat. Until the time should arrive when the same side is turned continually toward the tide-producing body, the progressive transfer of the tidal swell would produce at any given point not too near the poles, periodical movements of the planetary crust. The daily effects of these disturbances might in part be stored up in the form of strains and tensions which, modified and probably intensified by general shrinkage, would, at longer and at irregular intervals, become too great for the planetary structure to endure, and would thus eventuate in sudden and violent uplifts or collapses, and at times, in the opening of vents for the escape of internal heated substances. These violent strains and sudden movements would be most likely to occur after the attainment of a high state of rigidity in the crust, and the formation of permanent inequalities of considerable magnitude.

7. *Marine Tides in the Early History of a Planet.*— The marine tides produced in the early history of a planet must sustain important cosmogonic relations. It has been already stated that the friction of marine tides upon shores and the bottom of shoals must tend to diminish the velocity of a planet's axial rotation. It has also been maintained that a similar result must ensue from the tidal effects produced in a viscid or even a solid planet, if not possessed of complete rigidity. As this cause of retardation is operative in every planet subjected to tidal action, it is supposable that the rotational velocity of any particular planet was higher in former periods than at present. As the rate of retardation must have been inversely as the ratio of the masses of the planet and its tide-producing

satellite or satellites (as well as inversely as the cube of the distance) it may be inferred that smaller planets, other things being equal, have suffered greater retardation than larger ones. The more rapid rotation of the larger planets of our system is in accord with this view.

If the rotational velocity of the earth is thus in process of diminution, from what rate of velocity did the diminution begin? According to the theory set forth in this work, the earth's rotary velocity was once such that the centrifugal tendency on the equator was equal to the force of central gravitation, and at that time the matter of the moon separated as a nebulous ring. An equilibrium of centripetal and centrifugal tendencies would be reached at the present terrestrial equator if the earth's rotation were increased seventeen times.* But in the nebulous condition in which annulation is supposed to have taken place, the radius of the earth's mass was much greater than at present, and hence the physical conditions of annulation would have been supplied by a much slower rate of rotation. The present radius of the moon's orbit cannot be assumed as the earth's radius at the epoch of annulation, since, as has been shown, the moon is now in progress of recession from the earth, and must have been so ever since the commencement of lunar tides on the earth's surface. Lunar tides must have begun as soon as the moon acquired a separate existence in such form that

* Let f = present centrifugal tendency at the equator, the time of rotation being t.

f' = centrifugal tendency when the time of rotation is t'.

g = present force of gravity at the equator.

g' = force of gravity in the absence of any rotation.

Then, since, in the same sphere, the centrifugal tendency is inversely as the square of the time of rotation,

$$f : f' :: t'^2 : t^2 ;\therefore t'^2 = \frac{f}{f'} t^2 = \frac{f}{g} t^2,$$

since f' is to become equal to g'. But the physical constant

$$f = 0.111255, \text{ and } g' = 32.200795,$$

whence $t'^2 = .003455\ t^2 = \frac{1}{289}\ t^2$ nearly,

and $t' = .05878\ t = \frac{1}{17}\ t$ nearly $= 1.41138$ hours.

its attraction was not exerted equally and simultaneously upon all meridians of the equatorial belt. A ring having its mass uniformly distributed would not produce a proper tide, though it would produce an annular elevation around the earth. But as soon as the centre of mass in the ring should cease to coincide with the geometrical centre, a tidal action would begin; and this would increase until the annulus should have become a spheroid. It seems entirely probable on physical grounds, that definite tidal action began, and that even the lunar spheroid began its work, when the lunar mass was much nearer the earth than at present. Guided by physical laws the geognostic student must, therefore, bear in mind the probability of some extraordinary tidal action in the early periods of the earth's history.

Mr. G. H. Darwin has developed in this connection some views of novel originality and interest.* Proceed-

* The following are Mr. Darwin's principal memoirs:

1. *On the Bodily Tides of Viscous Spheroids.* Proc. Roy. Soc., May 23, 1878; abstract, *Nature*, xviii, 265-6, July 4, 1878.

2. *On the Precession of a Viscous Spheroid.* British Assoc., Dublin Meeting, 1878; abstract, *Nature*, xviii, 580-2.

3. *On the Precession of a Viscous Spheroid, and on the Remote History of the Earth* (with the following):

4. *Problems Connected with the Tides of a Viscous Spheroid.* Proc. Roy. Soc., Dec. 19, 1878 (Phil. Trans., Pt. 2, 1879); abstract, *Nature*, xix, 242-3, Jan. 30, 1879.

5. *On the Secular Effects of Tidal Friction.* Proc. Roy. Soc., June 19, 1879; abstract, *Nature*, xx, 246-7, July 10, 1879.

6. *On the Secular Changes in the Elements of the Orbit of a Satellite Revolving about a Planet Distorted by Tides.* Proc. Roy. Soc., Dec. 18, 1880 (*Phil. Trans.*, Pt. 2, 1880, p. 731); abstract, *Nature*, xxi, 235-7, Jan. 8, 1880, erratum, p. 276.

7. *On the Tidal Friction of a Planet Attended by Several Satellites and on the Evolution of the Solar System.* Proc. Roy. Soc., Jan. 20, 1881; abstract, *Nature*, xxiii, 389-90.

8. *On the Stresses Caused in the Interior of the Earth by the Weight of Continents and Mountains.* Proc. Roy. Soc., June 16, 1881; abstract, *Nature*, xxiv, 231, July 7, 1881.

9. *On the Geological Importance of the Tides*, Nature, xxv, 213-4, Jan. 5, 1882.

10. *The Movements of Jupiter's Atmosphere*, Nature, xxx, 360-1, Feb. 16, 1882.

ing from the starting point already determined by the researches of Ferrel (1853), Helmholtz, Purser, Sir William Thomson and Delaunay, Mr. Darwin has attempted to retrace the course of tidal retardation of the earth's rotary motion through the long æons of the past. Having shown that the recession of the moon must keep pace with the retardation of the earth, it follows that at some epoch in the past the moon's distance was but a fraction of its present distance, and the lunar month was a corresponding fraction of the present month. The velocity of the earth's rotation was then much greater than at present, but not in the same ratio as the moon's orbital period was less. Hence the lunar month contained less than twenty-seven days. Tracing the relations of these motions farther and farther back, we find them approximating nearer and nearer to equal periods, and Mr. Darwin finds that this synchronism must have existed at the time when the moon's distance was about the sum of the two radii. He is led therefore to assume as the basis of a remarkable series of conclusions, that the moon actually did separate from the earth after the earth had attained the condition of a molten or plastic mass. The period of rotation of the earth at that epoch was, as he calculates, between two and four hours, and he assumes it at three hours. The epoch was not less than fifty-two million years ago — probably much more. That the earth's rotational period could not have been less than about three hours is manifest from the fact that a higher rate of rotation would have caused it, in the condition then existing, to fly into pieces, and the parts to separate from each other.

This is the juncture at which he supposes the moon to have originated from the plastic mass. But why did the terrestial mass separate into two parts so unequal, instead of many parts? The influence of solar tidal action must furnish the explanation. The sun was already in existence

before the moon, and a solar tide rolled around the nascent earth before it ever felt the lunar tide. The solar tide was comparatively diminutive, but it was real. The day being three hours long, each meridian experienced a solar tidal swell every ninety minutes. There existed at every point affected by this tide a vertical oscillation having a period of ninety minutes. But this is the period of natural oscillation or swing of the earth-mass. Every mass has a certain period within which an oscillation or swing would naturally be accomplished, and its successive oscillations, like those of a pendulum, would be performed in equal times. The rate of oscillation depends on mass, viscosity and elasticity. A mass as large as the earth would complete its swing in a period comparatively long. Considering it as a viscid body, calculation shows that its gravitational oscillation would be completed in about ninety minutes.* Now, suppose the tidal movement to coincide with the oscillation period; the rise and fall of the tide must tend to establish oscillations in the earth-mass. The tidal elevation would concur with the natural swing of the earth-mass; and, at a time when the centrifugal tendency was nearly equal to gravity, the concurrence of the tidal and oscillatory movements might quite overcome gravitation, and the tidally elevated mass might completely separate from the earth. As only the tidally elevated portion of the earth would be subjected to this joint influence, only this portion would separate, and the earth would not fly to pieces.† The rotary velocity which would

* Rev. O. Fisher says four or five hours. *Nature*, xxv, 243.

† I suspect a fallacy in this mode of reasoning. It might be correct if the solar tidal force could be conceived as applied successively upon the same side of the earth with intermissions every ninety minutes. An oscillation is a motion of matter in a definite direction. It must persist until a natural period is completed. The solar tide, when the sun's declination was zero, produced motions immediately successive in every direction around the circumference of the equatorial zone. How could such motions generate a vibration of the earth? An incipient vibration generated by the tidal influence in a certain direction at one

disrupt the earth as a whole into many pieces did not quite exist.

That two moons did not originate from the tide and anti-tide may be explained by the inferior elevation of the anti tide. It might be further explained on the principles just set forth if it could be shown that the period of the earth-oscillation was three hours instead of ninety minutes.

Such, according to Darwin's theory, must be regarded as the probable beginning of the lunar-terrestrial history. We might speculate as to the antecedents of this rapid rotation. The earth in cooling and shrinking from a nebulous state must, on the principle of equal areas, have undergone great rotary acceleration. This would be true whether the moon was disengaged as a nebular annulus, or later by a tidal disruption, as just explained. But we are not in possession of data enabling us to determine certainly which possible origin of the moon has been realized. There are, however, so many analogies, and so many physical considerations pointing to the origin of planetary and lunar masses through a stage of annulation, that there seem to be good grounds for doubting whether Mr. Darwin's primitive, though plausible, assumption represents an actual chapter in the evolution of the lunar-terrestrial mass. The doubt is strengthened by the impossibility of establishing a similar inference in the case of other planets.

Some special considerations, however, bear upon the question. The disengagement of a satellite, whether

moment, would be destroyed the next moment, by a change in the direction of the pull, and the inauguration of a new vibration in the changed direction. It would seem that the oscillative capacity of the earth must be nugatory at the crisis of a lunar birth. Nor does this adjunct appear necessary. If the moon originated as supposed, the solar tide alone was sufficient to determine the isolation of a mass. The centrifugal tendency continuing to increase, the time would arrive when gravitation would be overbalanced. It would of course be the most protuberant part of the equatorial belt which would first reach and pass the limit of equilibrium. That is, the mass uplifted in a solar tide must necessarily be the mass detached, regardless of any measure of oscillation in the earth.

through annulation or disruption, takes place when the rotational velocity of the planet has attained that crisis in which the equatorial centrifugal tendency equilibrates the gravitational. As the result of contraction, the rotational velocity increases, and the equilibrating rate is continually approximated. But meantime, two other actions are in progress, one of which opposes and the other limits the occurrence of a secondary birth. Solar tides always exist, and they always neutralize to some extent the tendency to accelerated rotation. And further, the process of cooling and condensation ultimately reduces the planet to a condition of fluidity, viscosity or solidity, in which the rate of rotation required for the disengagement of a satellite is so high that the formation of a satellite is no longer probable. Now, in planets near the sun, where the solar tidal action is great, we may easily conceive that the retarding action has been so strong that the requisite rotational velocity for the disengagement of a satellite was never attained. Accordingly, Mercury and Venus are without satellites. On the other hand, in the remote situations, where the solar tidal action is feeble, the rotary acceleration may have been so little impeded that two or more lunar births may have occurred before the planet passed the annulating phase of matter. This is the more likely from the superior energy of rotation possessed by larger masses. Accordingly, from Mars to Neptune, we observe planets attended by several moons. Between these two regions, that is, in the zone occupied by the earth, the influence of the solar tide may have been such as to delay the crisis until the planet had reached the molten or viscous stage. It is not impossible, therefore, that the circumstances of the disengagement of our moon were different from those existing in the case of other moons. It may be that our moon was thrown off from the semi-fluid terrestrial sphere, while the other moons of our system passed through the annular

stage. There are some good grounds, at least, as Mr. G. H. Darwin has shown, for supposing our moon originated as described. It is a curious fact, as the same mathematician has shown, that similar reasoning does not show that the satellites of Mars, Jupiter and Saturn originated in a similar way.*

However the question of the annular origin of our moon may be decided, we have adequate reason for believing that the earth and moon were formerly in such relations that the lunar tidal effect was very much greater than at present. On the Darwinian premises, Professor Robert S. Ball,† of Dublin, has lately advanced the opinion that enormous lunar tides were produced upon the earth during the Palæozoic ages. He thinks it not unreasonable to suppose that during Palæozoic time the moon's distance was not over one-sixth of its present distance from the earth. As the moon's tide-producing effect is inversely as the cube of the distance, at one-sixth of the present distance the effect must have been 216 times as great as at present. If, therefore, the modern oceanic lunar tide is assumed as three feet, the oceanic tide with the moon only 40,000 miles distant, must have risen 648 feet.‡ Such a conception is startling. Such a rise and fall of the ocean-level along a continental shore would pour over the land twice a day a volume of water whose power and destructiveness it is impossible to picture. Such a rise in the Atlantic Ocean would send a flood up

* G. H. Darwin, *Proc. Roy. Soc.*, Jan. 20, 1881.

† In a lecture delivered before the "Midland Institute," Birmingham, England, October 24, 1881, and published in *Nature*, xxv, 79-82, 103-7, Nov. 24 and Dec. 1, 1881. Prof. Ball is Andrews Professor of Astronomy in the University of Dublin, and Royal Astronomer of Ireland.

‡ The linear height of the tide, however, is not quite proportional to the tidal force. It might be added that with the moon at such a distance, the terrestrial day would have been about seven hours. This increased frequency would increase the effects of denudation in three ways: (1) By the greater volume of the water acting; (2) by the greater frequency of its action; (3) by the greater velocity of its motion during the rise and fall of the tide.

the St. Lawrence River to Niagara Falls—into Lake Erie and all the way round to Chicago. It would convert all New England into an archipelago. All the cities of our eastern slope would be inundated. The great "bore" would roll up the Mississippi nearly to St. Paul. St. Louis, Memphis, Vicksburg and New Orleans would be submerged. The greater part of all the Gulf states would, for a few hours, be sea-bottom. Then the level of the ocean would rapidly subside. The waters would be poured back from the continent with the powers of a mighty flood. All the channel-ways would be rapidly deepened, and enormous volumes of sediment would be carried out to sea. Then the tide would surge back and the vast scouring process would be repeated. Well might the originator of the conception claim that if astronomy could ever prove the existence of such tides during Palæozoic time, some of the views of geologists would be "absolutely demolished." Sir Charles Lyell argued that the events of Palæozoic time were produced by such agencies as we now behold in action. Enormous sedimentation took place, but modern geologic forces are adequate, he thought, for its accomplishment, if we give them unlimited time. But physical science, as we shall see, does not allow the geologist unlimited time. He must shape his theories to a certain measure of time. Now here, exclaims Professor Ball, is the key to the whole matter. The 40,000-mile moon set the tide to work with two hundred-fold energy, as compared with modern tides, and all the sedimentation was accomplished easily within the time allotted by astronomy.

But now the geologist reëxamines the data which belong to his province of investigation. If, during Palæozoic time such terrestrial tides tore through the land, some records of their tremendous destructiveness must be preserved. Do we find them? Do we find the Palæozoic

strata composed of such enormously coarse materials as must have been spread over portions of the ocean's bottom by the hypothetical high tides? Do we find the sediments disposed in that state of confusion which must have resulted from such violent movements of the waters? We are compelled to reply in the negative. This may almost cause a feeling of regret, since Prof. Ball's theory is so ingenious, so beautiful and so apt. But the truth, when we find it, will be equally beautiful and equally apt. The Palæozoic sediments have been deposited, for the chief part, in quiet seas. The deep beds of limestones and shales are spread out in sheets continent-wide, which testify unmistakably to placid waters and slow deposition. Even the sandstones and grits give no evidence of such tremendous agitations of sea and sediments as 600-feet tides would imply. If such tides ever existed, it was anterior to the Palæozoic ages.*

But if Professor Ball has erred in locating such tides in Palæozoic time, it may only be an error of location. Before Palæozoic time were other vast æons of duration, and vast processes of sedimentation, of which we have but a dreamy and ill-defined conception. Here, certainly, was scope enough of time and space for 600-feet tides to carry on their work. Do the Eozoic strata afford any stronger evidence of so rapid and violent accumulation as such tides would imply? The response which they render to this inquiry must still be regarded as negative. Their condition, however, seems to carry us back to an

*Such views have been published by Professor J. S. Newberry. See *Trans. N. Y. Acad. Sci.*, Jan., 1882; *Nature*, xxv, 337, Feb. 16, 1882, and xxvi, 56, May 18, 1882. Mr. Darwin himself dissents from Professor Ball's application of his theory, in *Nature*, xxv, 213-4. Compare, also, on this subject, C. Callaway, *Nature*, xxv, 385; A. Hale, *ibid.*; J. V. Elsden, *Nature*, xxv, 409; Haughton, *Proc. Amer. Assoc.*, Montreal, Aug. 28, 1882. Professor Ball replies to his critics in *Nature*, xxvii, 201-3, Dec. 28, 1882. Mr. J. G. Grenfel also argues that high tides would deposit fine sediments (*Nature*, xxvii, 222), but he overlooks the *inland* action of a rushing tidal flood.

age when greater violence prevailed than characterized the subsequent Palæozoic time. It is easy to suppose that the manifest tumult of Eozoic time was only the subsidence of a greater tumult in a still earlier age. Certainly, it must be admitted that most of the materials of the Eozoic rocks are coarser, and seem to have been more rapidly accumulated than those of any later system. Here are conglomerates containing rounded, flinty constituent masses, sometimes of huge dimensions. And the enormous thickness of these primitive strata exceeds by far any thickness known among later sediments. At the same time we find vast masses of crystalline limestone interstratified among the oldest rocks known; and we are accustomed to refer such sediments to periods of comparative quiet. It is doubtful if even in the deep sea comparative quiet could be said to reign where the surface rises and sinks 600 feet every eight hours. Manifestly, any high tides of Eozoic time would not have been intermitted for the deposition of calcareous materials, to be afterward reëstablished. On the whole, the general aspect of the lithological masses of Eozoic time is such as might most reasonably be ascribed to agencies like those operative in sedimentation in modern times. We must admit, however, that they were generally more energetic, though at intervals their violence subsided to a state of limestone-making repose. The necessary characteristics of extraordinary tidal action are not distinctly manifest in the oldest strata that have been exposed to our investigation.

But it is not necessary, even yet, to renounce the conception of primitive high tides. There is no evidence whatever that the oldest strata ever exposed to human study are the oldest that ever existed. The conglomerates even of the Laurentian are but the ruins of some older sedimentary rocks. To what greater depth sedimentary strata extend we can only conjecture. Perhaps

they reach down to the zone of temperature where all rocks are at a molten heat, and perhaps in a molten condition. It may be that in these deeper and older beds would be discovered the evidences of accumulation under the agency of tides enormously high. It is even conceivable, if not probable, as we shall hereafter see, that a large portion of the oldest sediments ever deposited has been reduced again to a state of fusion, and that in these wasted primitive beds were impressed the evidences of high tidal action.

But whatever the rocks may testify, or may be conceived capable of testifying, the fact of the slow recession of the moon leads necessarily to the inference that the astronomical condition of enormous tides must have existed at some time in the past. If the ocean was then in existence, it experienced this enormous tidal action, and its records were written in the sediments of the time. If shores existed they underwent enormous denudation. If shores had not yet arisen, the shallows of the universal ocean must have been stirred.* If this proximity of the moon had been greatly reduced before the ocean accumulated, then the vastly more energetic tidal action was exerted upon a terrestrial globe of plastic or molten material. In this case we should have all the more reason to expect the formation of those meridional or submeridional trends discussed in other portions of this work.

While, however, the evidence appears to be slight that such tides as Professor Ball conceives have ever existed during the earth's sedimentary history, we may readily admit that Eozoic and Palæozoic tides existed sufficiently

* But there is, after all, one consideration which negatives the existence of enormously high tides since any process of sedimentation began. Such tides could have existed only when the earth had a rotation so rapid that its ellipticity of figure would have been considerably greater than at present. But Sir William Thomson has shown, as he thinks, that no great change has taken place in the ellipticity of the earth since solidification began. (Thomson and Tait: *Nat. Phil.*, § 830.)

high to operate with much greater energy than modern tides. When the moon was 48 earth-radii distant instead of 60, as at present, the length of the day, according to Darwin's method of computation, must have been about 16 hours; and the tide-producing power must have been twice its present power. But the erosive energy of the tide is as the square of its height, or inversely as the sixth power of the moon's distance.* The energy of tidal action would therefore be doubled by a diminution of the moon's distance by only one-fifth. This is a diminution which may be conceived to have existed within that time which on other grounds we are at liberty to ascribe to the remoteness of the Eozoic and Palæozoic stages of terrestrial development; and the corresponding double tide is one which would have quadrupled the energy of tidal action without working any greater confusion in the order of the sediments than the actual condition of the strata seems to imply. This consideration enables us to reduce Eozoic and Palæozoic time to one-fourth the duration indicated by the present rate of tidal erosion.

Tidal erosion, however, is certainly not the principal agency in the disintegration of rocks and the formation of materials for sedimentary processes, though the contrary view was held by the older geologists, and is still held by some.† Atmospheric and fluviatile denudation, extend-

* If d and d' be two different distances of the moon, and h and h', the corresponding heights of the tides, and E and E′ the corresponding rates of retardation of the earth's rotation, then, supposing the linear height of the tide to be in the simple ratio of the moon's tidal efficiency,

$$h : h' :: d'^3 : d^3, \text{ and } h^2 : h'^2 :: d'^6 : d^6.$$

If the two distances are 60 and 48 earth-radii,

$$h : h' :: (48)^3 : (60)^3 = (4)^3 : (5)^3 = 1 : 2 \text{ nearly.}$$

Also, $$E : E' :: h^2 : h'^2 = d'^6 : d^6.$$

But the erosive power of the oceanic tide results from the same friction which acts as a retarding agency, and hence the efficiency of tidal erosion is as the square of the height of the tide, or inversely as the sixth power of the distance of the tide-producing body.

† Von Richthofen: *China*, Vol. ii.

ing over the entire surfaces of continents, plays perhaps, a more important part than has generally been conceived. I shall cite hereafter, some recent views concerning the rate of denudation of various hydrographic basins. In this connection I desire only to state that atmospheric, fluviatile and torrential actions must have been materially augmented at the time when the moon's distance was 48 earth-radii, and the day was 16 hours long. It is manifest, as Mr. G. H. Darwin has reminded us, that "on similar planets at equal distances from the sun, and with the same depth of atmosphere, the linear velocity of the wind should vary as the linear velocity of a point on the planet's equator." At the time when a terrestrial rotation occupied but 16 hours, the trades and anti-trades must have travelled with a velocity fifty per cent greater than at present. We can readily conceive the probability that atmospheric movements so much more rapid must have augmented correspondingly the efficiency of wave-action and the disintegrating power of the rains, and at the same time have greatly increased the volume of precipitation and the frequency of storms. Such aggravated intensity of meteorological forces must have been coincident with the superior energy of tidal erosion. Both causes in concurrence must, beyond question, have expedited materially the geological work whose records are preserved in our oldest strata.

The subject of high primitive lunar tides has been here considered in more especial relation to the lunar-terrestrial system, because the data and the evidences of such action would be more accessible in this case. But the question is one of general and cosmic significance, and occasion will again arise to refer to the subject in connection with the present condition of the planet Mars.

§7. LIQUEFACTION OF WATER.

Subsidence of temperature to the point where water should pass from the gaseous to the vaporous condition must constitute an epoch of the utmost significance in the early life of a planet. That point on the earth is 212° Fahr. or 100° C., at the level of the sea. But it is well known that as the pressure diminishes, as in ascending a mountain, the steam point is lowered, while an increase of pressure raises the steam point. In fact, it has lately been claimed by Mr. T. Carnelly that water may be subjected to such pressure that it not only does not become steam at 212°, but does not even become liquid.* The well established facts indicate that on a planet of small mass, and correspondingly low atmospheric pressure, aqueous condensation would not take place until the temperature had subsided below the terrestrial standard; while on a planet of larger mass than the terrestrial, condensation would begin at a temperature above the terrestrial standard.

The temperature of the solidifying point also varies with the pressure. Professor James Thomson first concluded, on theoretical grounds, that when a substance expands in passing from the solid to the liquid state, the temperature of liquefaction is raised by increase of pressure; and when it contracts in liquefying, as in the case of ice, the melting point is lowered by increase of pressure. This deduction was experimentally verified by his brother, Sir William Thomson,† who found that the melting point

*T. Carnelly, *Nature*, xxii, 435, where he announces an experiment in which solid water (called "ice") exists at a burning temperature. See also, *Nature*, xxiii, 264, 288, 341, 383, and especially communications by O. J. Lodge and J. B. Hannay, pp. 504 and 505. See finally, *Proc. Roy. Soc.*, 6 Jan., 1881, cited in *Amer. Jour. Sci.*, III, xxi, 385-90.

†Sir W Thomson, *Phil. Mag.*, III, xxxvii, 123; *Poggendoff's Annalen*, Bd. lxxxi, S. 163. See also, *Trans. Geol. Soc., Glasgow*, vi, 41-2. The following is, perhaps, the *rationale* of the law: A certain amount of pressure seems to be

of ice is lowered 0°.059 C. for a pressure of 8.1 atmospheres, and 0°.129 C. for a pressure of 16.8 atmospheres. Mousson*, also, proved that ice melts at −18° to −20° C., when subjected to a pressure of 13,000 atmospheres; but it was not shown that all this pressure was necessary. Clausius subsequently showed, from theoretical considerations, that the freezing point of water must be lowered 0°.00733 C. for every atmosphere of increased pressure — a result which agrees with experiment.† Diminished atmospheric pressure would therefore raise the freezing point of water; and we might conceive the pressure so diminished that the lowered steam point would coincide with the elevated ice point. Under such circumstances, water would present the same relations as certain substances on our planet which never liquefy, but pass directly from the solid to the gaseous state when heat is applied.‡ On such a planet there could be neither clouds,

requisite to restrain the molecules of a solid, within certain limits of temperature, from relaxing their bonds to each other; the same as a certain amount of pressure, within certain limits of temperature, is necessary for restraining the molecules of the fluid from flying apart — the pressure in all cases being external. If the state of looser union requires more space, increase of pressure opposes the change of state, and a higher degree of intermolecular repulsion is required. Increased heat furnishes this. If the state of looser union requires less space, increase of pressure helps to reduce the body into such diminished space, and hence less repulsive energy among the molecules is required. That is, the temperature of fusion is lowered. Why a state of looser union requires less space (higher density) may perhaps be explained by the existence of larger intermolecular intervals, where, as in ice and most solids, the structure is crystalline — that is, having the molecules arranged according to a geometrical method.

Under this law the solidification by enormous pressure of molten mineral substances at temperatures above their fusing points cannot be conceived as a crystalline solidification resulting from a certain adjustment of temperature and pressure, but solidification resulting from the approximation of the molecules under the same amorphous arrangement as characterizes the liquid. Hence the state of solidity from pressure implies a higher density than the fluid state, while solidification from cooling implies a lower density than the fluid possesses.

* Mousson, *Pogg. Annal.*, cv, 161.

† R. Clausius: *Die mechanische Wärmetheorie*, 2d ed., i, 173. If we multiply 0°.00733 by 8.1 and 16.8 we get 0°.059373 and 0°.123144 — results practically identical with Sir William Thomson's.

‡ Compare Clausius: *Wärmetheorie*, I, Absch. vii, § 6, *Uebergang aus dem Festen in den luftförmigen Zustand.*

rain nor seas. Water would be born out of steam, in a solid snowy state, would descend like a shower of dust, and rest forever as rocky material. On a planet larger than the earth, where liquefaction from aqueous gas or invisible steam takes place at a higher temperature, the water must not only be hotter, but, under the higher pressure, must absorb a larger proportion of gaseous substances. From both these causes, meteoric water on such a planet must be a more efficient chemical agent, and must act with increased energy on the rocky substances of the planet.

As to substances which expand in passing from the solid to the liquid state, only a few experiments have been made. In fact, there are very few substances of which it is certain that such expansion takes place. Those experimented on are spermaceti, paraffine, stearine, wax and sulphur; and it has been proved that the melting point is universally raised by pressure.* Sir William Thomson, as before stated, inclines to the opinion that ordinary rocks belong to this class; but I think I have cited sufficient evidence that they belong to the same class as water, and hence have their solidifying point lowered by increase of pressure.

But, returning to the inaugurative stage of planetary hydratation, we can easily conceive the progressive advance of water formation on a planet. The first condensation would be revealed by the filmiest clouds in the highest and coolest region of the atmosphere. On a planet of the mass of the earth, or larger, it would seem probable that the crust must still exist in a state of incandescence.† Such questions are within the reach of mathe-

*Hopkins, *Report Brit. Assoc.*, 1854, 57; Bunsen, *Pogg. Annal.*, lxxxi, 562.

†On the earth all substances retain a red heat till the temperature falls below 977° Fahr. (J. W. Draper, *Amer. Jour. Sci.*, 67, January, 1877.) It is supposable that though the crust might have attained a dark temperature, the formation of a blanket of clouds would so arrest radiation that a glowing heat might be again imparted to the crust.

matics. On a small planet condensation would not begin until the surface had passed the stage of incandescence.

The accumulation of aqueous vapor in the higher regions would continue until the cloudy mass had settled through increasing density, to lower regions. Each stage of encroachment on the lower strata of the atmosphere must cost the clouds volumes of vapor dissipated into gas. Meantime the light of the sun becomes completely excluded, and the planet must be palled in impenetrable darkness, unless the ignited crust send its lurid gleam to redden the black vault of curling and threatening vapors. Eventually the condensation must reach such a point that the heat of the atmosphere can no longer prevent the rains from descending. Ages may elapse before a drop can penetrate to the planet. Ocean volumes may be dissipated into steam in mid air; but larger oceans must return to the conflict with the heat. Meantime the equilibrium of the electrical forces is disturbed, and sheets of lightning glimmer through the stormy air, and thunders ever renewed must jar the fabric of a world, and shake its watery pall to ever-augmented precipitation.

The forces of heat in the progress of such a storm, must undergo increasing wastage. Radiation is more vigorous, now that the cool sheet of clouds has marshalled its attacking rains in closer proximity. Convection steals away immense volumes of heat, as the stream of new-made vapors rises perpetually to the cooler regions. The crust at length glows with a dimmed ruddiness, and then the last ray of the planet's solar character expires. The secular storm, with a terrific grapple of the elemental forces, settles down on the seething surface, and holds possession with the grim violence of lightnings and floods. In this last struggle the ocean is born, and begins to stretch its liquid arms around the world. It is a boiling, bubbling, ocean. It saturates the atmosphere with columns of pale

steam. It is an ocean of acid waters. Not content to vanquish the powers of fire in their very intrenchments, they begin to disintegrate and destroy the rocky substance of the intrenchments themselves. A new war springs into existence. The chemical affinities turn their hands against each other, and rapes and robberies and reprisals make the subaqueous history of a planetary age.* Out of these reactions come the salts which the sea holds in solution. Out of these reactions come the earliest precipitations on the ocean's floor.

The continued progress of cooling effects, sooner or later, the transfer of the body of water from the atmosphere to the planetary surface. Through the thinned clouds gleams the sunrise of another æon. At length the exhaustion of the clouds reveals again the ancient sun, and the purified sky, and the action of the planetary drama now proceeds in the silent depths of the waters.

§ 8. TRANSFORMATIONS OF THE PLANETARY CRUST.

There must be a fire-formed crust on every planet. The floor on which the first ocean rests can have no other than an igneous origin. To tell me that no geologist has ever seen the earth's primeval crust does not shake my conviction that thus "the solid earth began." There are good reasons for not entertaining the expectation of ever looking upon any exposure of the original fire-formed crust. It no longer exists. Nor indeed, can we believe that even the oldest ocean-formed rock-strata on our planet have been preserved from destruction. At the commencement of sedimentation on any planet, the crust has attained such thickness that a temporary equilibrium exists be-

* These chemical reactions in the primeval history of the earth have been especially studied by Dr. T. S. Hunt. See his *Chemical and Geological Essays*. See also, an outline of these reactions in the present writer's *Sketches of Creation*, ch. vi.

tween the thermal action within and the refrigerative action without. The crust presents such a protection to the included heat that no further thickening is demanded, except as the mass of the planet cools. A thinner crust would expose the internal heat to more rapid radiation, and new layers of crust would be added to the under side. A thicker crust would give the included thermal forces the ascendency, and some layers would be melted from the under side until the facility of thermal conduction and radiation should be sufficient to exhaust the surplus energy of the heat within.

Now if, while such a crust exists as equilibrates the action of internal and external forces, a sheet of oceanic waters overspreads the surface; still more, if layers of marine sediments become accumulated, the crust will experience such a thickening that the forces of heat will preponderate, and by fusing some of the under layers reduce the crust to the equilibrating thickness. The continued accumulation of sedimentary deposits will be accompanied by the continued encroachment of a fusing heat upon the under side of the crust.* It is plain that the continuance of these processes is liable not only to remove and re-fuse totally the whole thickness of the fire-formed crust, but also, any assignable thickness of the sedimentary or super-crust. This process may continue during the whole of the planet's refrigerating history, though at no time can the encroachment at the bottom quite equal the sedimentary additions at the surface; since because the planet is necessarily cooling as a mass, its crust must experience a net increase of thickness. The final result

* This idea seems to have been first shadowed forth almost simultaneously by Professor Charles Babbage and Sir John Herschel, in 1836, 1837 and 1838 (see *Ninth Bridgewater Treatise*, App. G; also *London and Edinb. Phil. Mag.*, v. 213). Sir John's suggestions are embodied in the *Ninth Bridgewater Treatise*, App. I, in three letters, dated Feb. and Nov., 1836, and June, 1837. See also Leonhard's *Jahrbuch*, 1838, 98; 1839, 347.

might be that sedimentary beds, accumulated even after the dawn of the organic epoch, might come to occupy the lowest position. Organic forms comparatively high might seem to begin the succession of life by holding position in

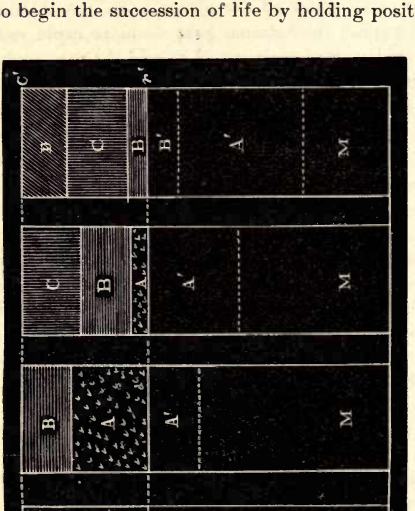

Fig. 47.—Ascent of Isothermal Planes in a Planet's Crust.

the oldest accessible rocks. Thus the palæontological investigator would be foiled by an illusion.

These changes are illustrated by the accompanying diagram, Figure 47. The line $c\,c'$ represents the bottom of

the sea, on which sediments are in process of accumulation. Under some circumstances the ocean basin would thus undergo a process of filling, and the sea-bottom $c\,c'$ would occupy successively higher positions. This would be the case if the general configuration of the planetary crust were to remain unchanged, the material deposited in the sea being only the amount removed from the land. In most cases, however, slow wrinkling would be in progress, so that the ocean's bottom would suffer a gradual subsidence. Let us assume that the bottom $c\,c'$ remains at a constant level notwithstanding sedimentary accumulation, the sinking being equal to the amount of sedimentation. Then let $c\,r$ or $c'\,r'$ represent the constant thickness of crust determined by the thermal conductivity of the crust-materials. A, on the left, represents a section of the fire-formed crust, and M, a portion of the underlying molten matter.

Now, if marine sedimentation accumulates the layer B, the ocean bottom retaining its level, a portion of A represented by A', will be sunken into the molten mass M, and reduced to a state of fusion. If another sedimentary layer C, is laid down, nearly the whole of A may be sunken and merged into the fused mass M; and the heat conducted into B will partially obliterate its stratification by crystallization and other modes of metamorphism. If, thirdly, we suppose the layer D to be deposited and sunken, the whole of A may now become merged in the molten mass, and a portion of B represented by B' will suffer the same fate. The remainder of B will become highly metamorphosed, and similar action will extend upward into C. Evidently, the same process may continue until some fossiliferous formation becomes sunken to the line $r\,r'$.

The line $r\,r'$ marks the isothermal plane at which the temperature is at the fusing point of the rocks. Planes of lower temperature pass through the planetary crust in

positions above this and approximately parallel with it. The mass M, below, as before stated, may be assumed as nearly uniform in temperature to the planetary centre. The progress of sedimentation thus appears to cause a relative ascent of the isothermal planes through successively newer formations in the planetary crust.

§ 9. PLANETOGRAPHIC EFFECTS OF CERTAIN CHANGED ASTRONOMICAL CONDITIONS.

1. *Changes in Velocity of Rotation.* — It has been shown that one of the actions of tides upon a planetary body tends to diminish its rate of rotation. Correspondingly, its equatorial protuberance will tend to diminish. In the case of a planet still retaining its liquid condition, the equatorial subsidence will keep nearly even pace with the retardation. To whatever extent viscosity exists, the subsidence will *follow* the retardation. There will exist an excess of protuberance beyond the equilibrium figure due to the actual rotation, and this will act as an additional retardative cause. In the case of an incrusted and somewhat rigid planet, the excess of ellipticity would attain its greatest value. It would continue to augment until the strain upon the mass should become sufficient to lower the excessive protuberance to the equilibrium figure. The recovery of this figure might take place convulsively. The equatorial regions would then subside and the polar would rise. In the case of an incrusted planet extensively covered, like the earth, by a film of water, retarded rotation would be attended by a prompt subsidence of the equatorial waters, and rise of the polar waters to about twice the same extent. In other words, the equatorial lands would emerge and the polar lands would become submerged. The amount of emergence would diminish with increase of distance from the equator, and the amount of submergence would diminish with increase of distance

from the pole. In about the latitude of 30° the two tendencies would meet and neutralize each other. Under these conditions, an incrusted and ocean-covered planet, since it must be undergoing a process of rotary retardation, must possess the deepest oceans about the poles, and the shallowest about the equator. The first emergences of land, accordingly, will take place within the equatorial zone; and the highest elevations and greatest land-areas will exist within that zone. The elevation of equatorial land masses would interpose new obstructions to the equatorial ocean current. This would divert it in new directions, and thus modify all climates within reach of oceanic influences. Changes of currents would necessitate the migration of marine faunas, and changes of climate would modify the faunas and floras of the land.

But the protrusion of the equatorial land-mass could not increase indefinitely. The same central force which retains the ocean continually at the equilibrium figure, strains the solid mass in the same direction. The strain must at length become greater than the rigidity of the mass can withstand. The equatorial land protuberance will subside toward the level of the ocean. Some parts of the ocean's bottom must correspondingly rise. Naturally, the parts about the poles will rise most. Thus some equatorial lands will become submerged and some northern and southern areas may become newly emergent.

But these vertical movements would not be arrested precisely at the point of recovery of the equilibrium figure. As suggested by Professor J. E. Todd*, and less explicitly by Sir William Thomson, the movement would pass the equilibrium figure to an extent proportional to the cumulation of strain. The equatorial region would become too much depressed and the polar regions too much elevated. The effect of this would be to accele-

* Todd: *Amer. Naturalist*, xviii, 15-26.

rate the rotation sufficiently to neutralize the ceaseless tidal retardation. The day would be shortened. The ocean would rise still higher along the shores of equatorial lands, and subside along the shores of polar lands. An extension of polar lands would immediately modify the climates of the higher latitudes. They would become subject to greater extremes. A considerable elevation of polar lands would diminish the mean temperature, and the region of perpetual snow would be enlarged. These effects would visit the northern and southern hemispheres simultaneously.

Such effects would follow from an excessive subsidence of equatorial lands. But the constant retardative action of the tides would cause the equatorial lands again to emerge, and protrude beyond the limits of the equilibrium figure attained in a later age. Thus the former conditions would return, and the former events would be repeated. In the nature of force and matter, these oscillations should be repeated many times. Professor Todd suggests that the present terrestrial age is one of equatorial land subsidence, and of high latitude emergence. Immediately preceding the present, the Champlain epoch was one of northern and probably of south polar subsidence; while further back, in the Glacial epoch, we have evidence of northern and perhaps also of south latitude elevation. He thinks the series of oscillations may be traced backward to the epoch of the earliest solid records of the earth's changes.

The periodical elevation and subsidence of the equatorial and polar regions would change the positions of ocean currents, and consequently the oceanic temperatures in given situations would be changed. Change of depth alone would result in change of temperature, since recent researches have shown that the abysses of our oceans are filled with water possessing a polar temperature, while

shallower seas possess temperatures graduated to their depth, and influenced near the surface by the latitude. Changes of oceanic temperature, produced by either of these causes, would lead to the extinction or migration of faunas. As the movements here contemplated are cyclical, the same conditions would recur again and again; and accordingly the same fauna might return again and again to the same region, with intervals of occupation by another fauna. Progressive sedimentation would preserve the records of such faunal alternations; and there would be presented the phenomena of "colonies," "reapparitions," and other faunal dislocations in the vertical and horizontal distribution of fossil remains. These phenomena are well known to the student of geology.* The progressive regional differentiation of lands and seas due to the secular loss of planetary heat would be a cumulative cause of slow but inevitable changes in the fauna at its successive recurrences, and would limit the number of recurrences of the same fauna. This action would be most sensibly felt in shallower seas and on land. The depths of the ocean, which retain most uniformly their cosmic conditions, would witness the longest series of recurrences of the same or a kindred fauna.

2. *Retarded Orbital Motion.*—Strong deductive indications exist, as has been shown, that the orbits of the planets and satellites have been enlarged. Not to speak of other causes, this is one of the indirect effects of tidal

*M. Joachim Barrande, *Colonies* Bull. Soc. géol. de France, xvii, 602, 1860; *Défense des Colonies*, Part I, 1861; Part II, 1862; Part III, 1865; Part IV, 1870; Part V, 1881. Prof. James Hall, *Trans. Amer. Phil. Soc.*, 1866, p. 246, in advance of *Palæontology of New York*, vol. iv,—these views being repeated at meeting of National Academy, Hartford, 1867, and indorsed by Prof. L. Agassiz; A. H. Worthen, *Proc. A. A. S.*, xix, 172-5, 1870, Troy; but see Prof. Hall's criticisms, *id.*, xxii, 321-35, reprinted in Appendix to Twenty-seventh Rep. New York Regents, 117-31; Prof. H. S. Williams, *On a Remarkable Fauna at the Base of the Chemung Group in New York*, *Amer. Jour. Sci.*, III, xxv, 97-104, Feb., 1883, and Note, p. 311; but see S. Calvin, *Amer. Jour. Sci.*, III, 432-6.

action. Each planetary year has, in the remote past, been shorter than at present. In the same proportion, each season on each of the planets — if we may generalize the term season in a qualified sense — has been shorter. It ought not to be supposed that the epoch of sensibly shorter years has been so recent as to offer an explanation of the extreme longevity attributed to the "antediluvians." The shorter years, however, must have been experienced during the progress of the geological periods. Whatever actions accompany the transitions from summer to winter, and from winter to summer, must consequently have been more frequently repeated. All geological effects attributable to such actions must correspondingly have been augmented. Each round of the seasons brings its appropriate precipitations, erosions and disintegrations; and when these rounds were twice as frequent, geological changes were more rapid. Geological actions were also more energetic, in consequence of the rapidity of the transition from one climatic state to another. At the same time, also, the nearer proximity of the sun would bring a greater amount of solar heat, which is the prime mover in all the seasonal changes. Shorter years and shorter seasons imply different adaptations in the natures of animals and plants. The processes of seasonal reproduction were accelerated; and where the same work was done in less time, the functional powers must have moved with greater efficiency or greater celerity.

3. *Increase of Obliquity of Axis to Plane of Orbit.*— Another influence of tidal action inclines the planetary axis, within certain limits, at an increasing angle with the axis of the orbit. The most obvious consequence of this (which is augmented and diminished by changes in the plane of the orbit as compared with an invariable plane) is to widen the torrid and the frigid zones, and narrow the temperate zones.

In the subjoined diagram, N S represents the axis in one state of inclination. The date is the summer solstice of the northern hemisphere. R R are parallel solar rays whose points of tangency with the planet's surface, as at P, determine the position of the polar circles, and the limits N P of the polar zone; C, the central ray at this date, vertical at T, determines the position of the northern tropic, T T, and the breadth, T A, of the torrid zone, and T P, of the temperate zone.

Now suppose the inclination to be increased so that

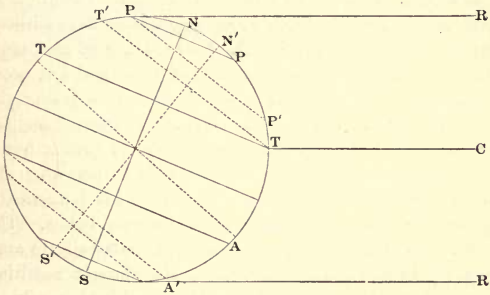

FIG. 48.—CLIMATIC EFFECT OF INCREASED OBLIQUITY OF A PLANETARY AXIS.

N′ S′ represents the position of the axis. Then N′ P′ will represent the limits of the polar zone, T A′ the width of the torrid zone, and P′ T, the width of the temperate zone. With an inclination of 45°, the temperate zone, in the sense here explained, would vanish.

The widening of the torrid zone would extend the range of products depending on a torrid summer climate, but would depress the winter temperature along the borders of the zone, since in winter the days would be shorter and the meridian sun would have less altitude. In other

words, the torrid summer would extend into higher latitudes; but the same latitudes would experience during winter a lower depression of temperature than they would with a less axial inclination. There would be a wider thermal contrast between the tropical summer and the tropical winter throughout the whole breadth of the zone. This circumstance would react upon the organic kingdoms. Plants and animals must endure greater extremes. Those most susceptible to climatic influences might become dwarfed or exterminated.

The widening of the frigid zone implies more sunshine in summer. The sun will attain to a higher elevation at every parallel, and the area enjoying summer days without a sunset will be enlarged. The consequence of this must be a more extensive disappearance of snow and ice, accumulated on planets with snow-capped poles during the previous winter. On the contrary, the increased inclination extends the area deprived of the sun in winter, but it does not increase the severity of the cold; since when the sun is a great distance below the horizon his influence is no less felt than when but a short distance below. The winter season would therefore not tend materially to augment snowy accumulations beyond the amount resulting from a low axial inclination. The combined result of summer and winter would be, in this view, a diminished amount of snow and ice. Correspondingly, a diminished inclination of the axis would result in an increased amount of snow and ice, though the area covered would be less. These consequences would be simultaneous in the two polar zones.

With no inclination the sun would be perpetually in the horizon of either pole. A temperature nearly that of external space would prevail uninterruptedly. But at no great distance from the pole, perpetual sunshine, though from a slanting sun, would tend greatly to the dissolution

of snowy accumulations. At 26° from the pole the altitude of the sun would be about the same as the midday sun at New York at the end of December. But it would remain permanently at that altitude. It is doubtful whether this position of the sun would be compatible with a snow cap extending lower than 26° from the pole. A slight inclination would throw an area about the pole into a state of sunlessness during a portion of the winter, but it would gain in altitude of sun during the summer. On the whole, it seems very doubtful whether any inclination, great or small, would create the conditions for a permanent ice cap reaching as far as the latitude of 40°.*

4. *Change in Relative Positions of Apsides and Equinoxes.*—The precession of the equinoxes arises from a slow gyratory motion of the axis of the planet, causing each pole to describe a somewhat regular circle. This results from the action of the sun upon the equatorial protuberance, joined to the resultant of the combined actions of the satellites, when they exist. The rate and amount of the disturbance is therefore connected, among other things, with the amount of the protuberance and the amount of the inclination. The effect of this change is to cause the planetary axis to be inclined, at different periods, in different absolute directions; and the total movement relative to a point in the planet's orbit is also affected by a motion of the apsides. In the case of all the planets except Venus (and possibly Neptune) the apsidal motion is direct, and therefore diminishes the effect of precession. In the case of the earth the equinoctial point falls back 50″.1 annually. It would of itself, therefore, complete the circuit of the ecliptic in twenty-five thousand, eight hundred and sixty-eight years. But as the apsis goes for-

*The reader will find some discussions of axial inclination as a cause of terrestrial glaciation in Drayson. *Quar. Jour. Geol. Soc.*, xxii; Thomas Belt, *Id.*, Oct., 1874, abstract, *Amer. Jour. Sci.*, III, ix, 313-5; Croll: *Climate and Time*, ch. xxv, where Drayson and Belt are discussed.

ward to meet it at the rate of 11″.24* annually, this would complete a revolution in one hundred and fifteen thousand, three hundred and two years. The approximation of the equinox and the apsis is the sum of these motions, 61″.34, and hence the equinox returns to the same position in relation to the apse in twenty-one thousand, one hundred and twenty-eight years. The earth's axis was inclined exactly from the sun at perihelion, in the year 1248. It now (1883) consequently points 10° 49′ 11″ back (or west) of perihelion, so that perihelion is reached about ten days after the winter solstice.

It results from these two secular movements that at a certain time, the planetary axis will lean toward the sun when at the aphelion point; at another, toward the sun when at the perihelion point. In the former case, summer occurs in the northern hemisphere during aphelion, and winter during perihelion. In the latter case, summer occurs in the northern hemisphere during perihelion, and winter during aphelion. The terms, of course, are inverted in reference to the hemisphere below the plane of the planet's orbit.

In the accompanying figure, let N S represent the axis of a planet from such a point of view that equator, tropical and polar circles are projected in right lines. Let the position of the planet be perihelion, with the solar rays R, C, R, coming from the right. The north pole leans toward the sun. *Summer* in the northern hemisphere and winter in the southern, occurs during perihelion. Next, suppose, in the same diagram, the north pole is turned away from the sun at perihelion, and the solar rays R′, C′, R′, come from the left. Now, *winter* in the northern hemisphere and summer in the southern, occurs during perihelion.

* The values of these variations are taken from the Encyclopædia Britannica, Art. *Astronomy*.

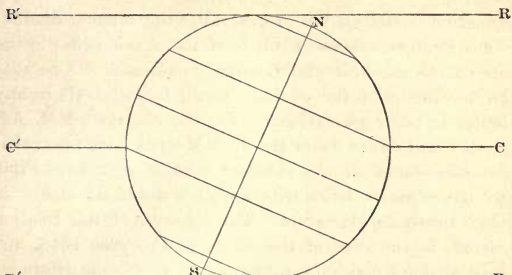

FIG. 49. CLIMATIC EFFECT OF CHANGES IN RELATIVE POSITIONS OF APSIDES AND SOLSTICES.

The planetary effect of such changes in the position of the axis during the summer and winter periods of each hemisphere, would be climatic. In the first case supposed, summer in the northern hemisphere concurs with the planet's greatest proximity to the sun. The solar action on the polar snow and ice, if they exist, would be greater than when summer occurs in aphelion, nearly in the ratio of the square of the perihelion and aphelion distances. In other words, the summer warmth would show greatest excess in planets having orbits of highest eccentricity; though the effect of superior eccentricity would be diminished with increase of mean distance from the sun, and increased with diminution of mean distance. The concurrence of the summer solstice with perihelion would therefore tend to diminish polar glaciation. During the aphelion winter, the solar action would be diminished, below the solar intensity during a perihelion winter, at all points having the sun above the horizon; but not sensibly changed at points having the sun below the horizon. The resultant effect throughout the polar zone would probably be some increase of glaciation. This winter increase of

glaciation would go far to neutralize the summer diminution. Professor James Croll is of the opinion that in the case of the earth, it would entirely neutralize it; so that the movement of the equinox would never result in any change in polar glaciation.* On the contrary, MM. Adhémar † and Julien ‡ and Mr. J. J. Murphy § maintain that the coincidence of the summer solstice with perihelion, and the winter solstice with aphelion would decidedly increase northern glaciation. The converse of this relation existed, in the case of the earth, in the year 1248, and these authors maintain, by means of numerous citations, that the winter climate of Europe was milder at that epoch than at present. The passage of the winter solstitial point ten or twelve degrees before the perihelion point already results, they say, in a perceptible increase of wintry cold. It is, however, scarcely credible that so trifling an increase of distance from the sun at the winter solstice should result in any perceptible change in the winter climate; or that the whole difference between perihelion and aphelion should ever cause such general glaciation of the northern continents as seems to have existed in a former geological period. This doubt may well be based on the summer influence of conjunction of summer solstice and perihelion. We are not in a position, therefore, to conclude that changes in the angle made by the line of equinoxes with the line of the apsides would cause any important residual effects upon planetary climate.

5. *Changes of Orbital Eccentricity.*—The immediate effect of increased eccentricity is to increase the differ-

* Croll: *Climate and Time*, 83; *Phil. Mag.*, Sept., 1869. On this subject, see also Arago, *Annuaire*, 1834, and *Edinb. New Phil. Jour.*, vi, 1834.

† Adhémar: *Révolutions de la mer*, 2d ed., 1860.

‡ Julien: *Courants et révolutions de l'atmosphère et de la mer.* See also, Le Hon: *L'Homme fossile en Europe*, 4me. ed., 1877, Seconde Partie.

§ Murphy, *Quar. Jour. Geol. Soc.*, xxv, 350.

ence between the perihelion and aphelion distances of the planet. Whatever climatic or other consequences proceed from this difference will be exaggerated by increased eccentricity. But the nature of the climatic effect will depend on the angle of the equinoctial line with the apsidal line, and also, whether a particular solstice occurs on the perihelion or the aphelion side of the equinoctial line. Let us suppose that the summer solstice of the northern hemisphere coincides with perihelion. Thus, with increased eccentricity, the perihelion distance in summer is less, and the summer, though shorter, is warmer; also the aphelion distance in winter is greater, and the winter is longer and colder. The winter will therefore accumulate more snow and ice, and the snow cap will extend to a lower latitude. But then this accumulation will be acted on by the increased summer heat. If, therefore, the accumulation is not sufficient to withstand this increased heat, no residual effect will remain. If any part of the accumulation is sufficient to continue through the hot summer, there will be a secular accumulation of northern snow and ice. But it must be mentioned that the solvent effect of the hot summer will not be proportional to the perihelion distance. The solar rays, falling on surfaces of snow and ice, will be exhausted first in the formation of vapor, which will obstruct the access of solar heat, and neutralize, to a large extent, the excess of summer warmth. The effective solvent force of the solar rays may not, therefore, much exceed their force at the aphelion distance, and there must remain a residual increase of northern glaciation. This, at least, is the view taken by Croll.* It does not appear, however, that the residual increase can ever amount, upon the earth, to "a reign of ice," such as prevailed in the Quarternary period

* Croll: *Climate and Time.*

of geology.* Mr. Croll himself does not maintain this; but he argues that in the case of the earth, the configuration of the continents has been such as to direct the equinoctial current, during the period of summer perihelion, away from the northern hemisphere, and thus indirectly to induce the conditions of a "reign of ice."†

It is manifest that the production of a state of northern glaciation by the concurrence of high eccentricity and a perihelion summer solstice would be attended by reciprocal conditions of climate in the southern hemisphere; and that all these conditions would be reversed by low eccentricity and an aphelion summer solstice. It is also manifest that each astronomical movement would produce a climatic cycle of its own — that connected with the eccentricity having a variable period of some tens or hundreds of thousands, and that connected with precession and the movement of the apsides having a period of about 21,000 years. When the effects from the two causes concur, a maximum climatic effect would result; when they conflict, a minimum.

* Sir J. Herschel, *On the Astronomical Causes which may Influence Geological Phenomena*, Geological Transactions, 1832; *Treatise on Astronomy*, § 315; *Outlines of Astronomy*, § 368; Arago, *Annuaire*, 1834, p. 199; *Edinb. New Phil. Jour.*, vi, April, 1834, 244; Humboldt: *Cosmos*, iv, 459, Bohn's ed ; *Phys. Descrip. Heavens*, 336.

† Croll: *Climate and Time*; A. Winchell: *Sparks from a Geologist's Hammer*, 175 99. See criticisms of Croll's theory by S. Newcomb, *Amer. Jour. Sci.*, III. xi, 263; J. J. Murphy, *Amer. Jour. Geol. Soc.*, xxv, 350, 1869, abstract *Amer. Jour. Sci.*, III, xlix, 115-18; Charles Martins, *Revue des Deux Mondes*, 1867; W. J. McGee, *Popular Science Monthly*, xvi, 810, but with general endorsement; C. B. Warring: *Penn. Monthly*, 1880. Further on this subject the reader may consult Le Hon: *L'Homme fossile*, pt. ii; Col. Drayson, *Phil. Mag.*, 1871, abstracted in *Amer. Jour. Sci.*, III, ii, 501; Sir William Thomson: *Geological Climate*, Trans Geol. Soc., Glasgow, Feb., 1877, vol. v, pt. ii; James Geikie: *Prehistoric Europe*, 1880; G. Pllar: *Ueber die Ursache der Eiszeiten;* Hirsch, *Sur les causes cosmiques des changements de climat*, Bull. de la Société des sci., nat. de Neufchâtel. Also, discussions by Croll, Heath. Moore and Pratt in the *Philosophical Magazine*, 1864, 1865. 1866; A. R. Wallace: *Island Life*. W. J. McGee has very recently vindicated the "eccentricity theory" in *Amer. Jour. Sci.*, III, xxvi. 113-20, Aug , 1883.

§ 10. OROGENIC FORCES.

The inequalities in the contour of the terrestrial surface are scarcely more familiar than the orographic phenomena which diversify the visible face of the moon with their lights and shades. The earth and the moon are equally well known to be marked by mountains, valleys and plains. The lights and shades of the disc of Mars are also generally received as evidences of analogous topographical configurations. In general, we might be led to believe from the study of terrestrial inequalities, and the terrestrial forces which seem adequate to develop mountain features, that the production of mountains is a common incident in planetary history. We can understand, at least, certain modes of action which tend toward mountain development; and even if no complete and satisfactory theory can yet be framed, it may be gratifying to the reader to learn what views have been entertained, and what is the present state of speculation on the subject.

In discussing the origin of mountains, and of terrestrial mountains in particular, it is necessary, first of all, to discriminate *mountains of elevation* from *mountains of relief*. The former are eminences which have been manifestly upraised above the general level of the earth's surface. The latter are saliences resulting from the erosion and removal of surrounding masses. The interpretation of erosive phenomena is something so simple that the explanation of mountains of erosion has given rise to little discussion. In almost every case, however, a mountain mass inaugurated by actual elevation has been greatly modified by much later erosions. In many instances, indeed, erosion has completely transformed the configuration of the original upheaval, and it has sometimes so disguised the results of upheaval as to require careful study to discriminate certainly the work which ought to be ascribed to

elevatory action. But in this connection we disregard entirely the sculpturing which has been performed on the surface, and direct our inquiries to the nature of those more concealed agencies which seem to have exerted themselves somewhere within the solid crust of the planet.

Movements of the earth's solid surface have been so often associated with volcanic phenomena that it is natural that mankind from time immemorial should have ascribed mountain formation to the agency of internal heat. The formation of mountains was, by the older geologists, considered explained by theories proposed to account for the phenomena of vulcanism; and there is unquestionably a close analogy between the seismic movements which often accompany vulcanic exhibitions, and the larger processes which have resulted in permanent mountain uplifts. Still, a slight consideration of the facts shows that the vast and systematic orographic convolutions of the terrestrial crust must have been produced by forces widely different in power and mode of action from the disturbing influences which result from igneous activities. There is reason, indeed, to consider whether these igneous manifestations are not, conversely, the result of movements in the earth's crust; and this is a question to which we will return in connection with molten conditions and melting forces upon our planet.

We will now proceed to give a concise exposition of the principal theories which have been promulgated respecting the origin of mountains.

1. *Theory of Upheaval by Aëriform Agents.*—The idea that mountains have been uplifted, and terrestrial disturbances produced by steam, gases, or other heated agents, is as old as Strabo,* and may even be traced to Anaxagoras,† who taught that earthquakes are "produced by the

*Strabo: *Geographia*, lib. vi.

†Diogenes Laërtius: *Lives of the Most Illustrious Philosophers of Antiquity.*

air which finds its way into the earth." An attempt was made to explain the origin of such mountain-raising agents, when Sir Humphrey Davy and others made appeal to chemical action as a source of heat, steam and gases. Sir Humphrey's arguments and experiments were in line with the current of new conceptions then flowing out of the new discoveries in chemistry, and for a time appeared extremely plausible. They were espoused by the distinguished geologist Daubeney, and for some years they commanded very general credence. Reflection, however, produced the conviction that the cause was insufficient in generality, endurance and efficiency. Gas and steam-production through chemical action has not probably existed on a scale sufficiently vast to account for mountain-ranges thousands of miles in length and thousands of feet in height. And whatever the magnitude of gas or steam production, the causes operative have not probably been sustained through periods sufficiently prolonged. Such causes are seen to be operative in our times no longer; as they seem to have ceased to exist, there is no ground for affirming that they ever continued in action — if they ever existed — for such length of time as is required by a history of mountain development stretching over æons of geological time. It is conceivable, indeed, that agencies of this kind have had the requisite persistence, but the general condition of our planet has remained comparatively unchanged through so many ages, while the evolution of mountains has continued, that very little probability exists that the equilibrium of the chemical forces had not been attained during the Archæan ages. But a further and more fatal objection to the present theory arises from the inadequacy of aëriform agents to do the work required. If mountains have been uplifted by steam or gases, those agents must have borne the weight of the mountains and overcome the resistances to motion presented by the rigidity

of the rocks. This action has been necessary, not only to uplift the mountains, but to maintain them. Now, this work demands both improbable persistence and impossible energy. The steadiness of mountains is not maintained upon reservoirs of wind. Nor have gases or steam the unlimited power of reaction, even at the highest temperatures, which is implied in bearing the weight of the Andes or Himalayas. Such weights would crush them into fluid, viscid, and practically solid states.* These objections apply to the agency of the aëriform condition of matter however produced. Steam originating from the penetration of surface waters to an assumed heated interior must be characterized by all the inadequacy of gases chemically originated. While, therefore, the power of confined steam and compressed gases is immense, and may even contribute something to the phenomena of earthquakes, their elasticity is undoubtedly limited far within the requirements of mountain formation.

2. *Theory of a Molten Nucleus and a Wrinkling Crust.*—If the primitive history of the matter of our planet has been such as set forth in the preceding portion of this work, there must have been a time when incrustation began, and there must have been a time when matter in the liquid condition interposed a continuous zone between the

*Compare Suess: *Die Entstehung der Alpen*, Wien, 1875, abstract in *Amer. Jour. Sci.*, III, x, 446-51; Dana: *Manual of Geology*, third edition, 747; *Nature*, xxi, 177, Dec. 25, 1879; J. D. Whitney, *North American Review*, cxiii, 255. It was shown by Bischof in 1839, that "the elastic force of steam cannot surpass a certain maximum, which it reaches when its density is equal to that of water;" and it has been calculated that this force would not in any case raise more than a column of lava seventeen miles high. The laccolitic mountains of Colorado are cases in which a moderate-sized mountain uplift seems to have been produced by the upward pressure of fluid hypogene matter; and this is the nearest approach known to mountain-making by a method of upburst. But these mountains are comparatively insignificant in dimensions, and there is no evidence of the intervention of the elastic force of vapors in their formation. (See G. K. Gilbert: *Geology of the Henry Mountains*, Powell Survey, 1877, *Nature*, xxi, 177.)

solidifying crust and the consolidated nucleus.* This was a time, too, when, according to the views entertained of nebular theory, the earth's rotation must have been much more rapid than at present, and the equatorial protuberance much greater. Thus, at the same epoch, the freedom of the protuberance to slip under the influence of nutational and precessional forces, and the condition of greater efficiency in the action of those forces, were much more marked than in subsequent epochs, when the earth's mass became bodily rigid, and the oblateness was diminished. But passing by the possible climatic consequences of a shifting of the terrestrial crust in relation to the axis of rotation, I wish only to indicate here the grounds of the theory that the simple process of cooling may have developed surface rugosities which grew into mountain magnitude.

The conception of wrinkling as an incident of terrestrial cooling seems to have been entertained by Descartes,† and was somewhat definitely enunciated by James Hall of Edinburgh, in 1812,‡ M. Elie de Beaumont,§ Prof. Sedg-

*Prof. James Hall says, nevertheless, that of the central mass of molten matter "we know nothing" (*Palæont. New York*, III.)

In a New York lecture of later date, before the American Institute, on the *Evolution of the American Continent*, he is reported to have said: "I desire to impress upon you this one truth, that we have not, in our geological investigation, succeeded in going back one step beyond the existence of water and stratification—one step toward this so-called primary nucleus of molten matter. * * * This original nucleus that has been talked about in geology *has produced no effect upon the surface of the earth; neither upon its mountain chains or any other of the great features of the continent.* (Report in *New York Tribune.*)

†Descartes: *Principes de la Philosophie*, pt. iv, §§ 41, 42, 1644. Descartes gives several illustrative figures, in one of which strata are shown uplifted and broken in a certain place, while on each side they are shown depressed.

‡James Hall, *Trans. Roy. Soc., Edinburgh*, vii, 79, 1815, read, 1812.

§De Beaumont: *Les Systèmes de Montagnes.* Successive mountain upheavals, in systems having each its own parallelism, "cannot be referred to ordinary volcanic forces, but may depend on the secular refrigeration of our planet." (*Ann. des Sci. Nat.*, Sep., Nov. et Dec., 1829; *Revue Française*, No. 15, May, 1830; *Bul. de la Soc. géol. de France*, iv, 864, May, 1847.)

wick,* M. Constant Prévost,† and William Hopkins;‡ but the most effective scientific support of this doctrine has been traced out by more recent writers. The starting point of the theory is in the unequal rate of cooling of the superficial and deeply seated portions of the earth, and further, the unequal contraction of differently heated bodies when cooling from different temperatures. Physical considerations have shown that some time after incrustation of a planet has begun, the rate of cooling at the surface will be somewhat slower than at some point beneath the surface, and that the surface may even retain a constant temperature, while the interior cools.§ Mr. G. H. Darwin has recently shown that the actual seat of most rapid cooling in the earth is probably about 100 miles below the surface, and that this point continues to descend as cooling progresses.‖ It is also well known that the rate of contraction of a more highly heated body is more rapid than that of a body of lower temperature, when both cool the same number of degrees. Now, for both these reasons, the contraction of the interior of the earth must be more rapid than that of the cooler and less rapidly

*Sedgwick, *Trans. Geol. Soc., Lond.*, Jan. 5, 1831, in a paper on the structure of the Cumbrian Mountains.

†C. Prévost, *Sur la Théorie des Soulèvements*, Bul. Soc. géol. de France, xi, 183, 1840, but taking a different view from de Beaumont. He ascribes the formation of mountains to "tangential pressures propagated through a solid crust, * * * and produced by the relative rate of contraction of the nucleus and of the crust."

‡W. Hopkins, *Address before the Geol. Soc. of Lond.*, 1853, *Geol. Jour.*, ix, lxxxix.

§Maxwell: *Theory of Heat*, 247; Sir W. Thomson, *Trans. Roy. Soc., Edinb.*, 1862; Thomson and Tait: *Nat. Phil.*, App. D. See an illustration of this principle by Rev. O. Fisher in *Nature*, xix, 173. M. Elie de Beaumont, applying Arago's observations on thermometers placed at various depths beneath the surface, to Poisson's formulas embodying the mathematical theory of heat, calculated that the epoch at which the cooling of the nucleus began to exceed that of the crust was 38,359 years after the commencement of incrustation. Hence it might be inferred that this epoch determines the date of the commencement of the process of wrinkling.

‖G. H. Darwin, *Nature*, xix, 313, Feb. 6, 1879.

cooling exterior layers. If, therefore, the exterior layers were perfectly rigid and infrangible, the interior would shrink away from the exterior, and open spaces would come into existence between them. But the nature of matter is such that a terrestrial film would be utterly incapable of sustaining its own weight if any adequate force were exerted to raise it into an arch having a span of some miles. The solid external film must therefore yield in some way so as to continue to rest generally, throughout its whole extent, upon the underlying nucleus. Under the enormous lateral pressure which would ultimately be developed, the crust may be conceived as either crushing together, or undergoing a process of wrinkling and fracture, combined in certain proportions. Either of these consequences may be conceived as somewhat uniformly distributed geographically, or as localized to a certain extent. The theory here considered supposes the result to take the form of wrinkling, and supposes it to be unequally distributed. If this conception represents the actual nature of the events, then wrinkles or folds of the planetary crust would arise which, in the course of ages, might naturally be conceived to grow into mountain dimensions.

The process of wrinkling through the action of lateral pressure is finely illustrated by spreading a layer of clay on a stretched sheet of India rubber, and allowing the sheet slowly to contract.* The sheet may be five-eighths of an inch (16 mm.) thick, $6\frac{3}{4}$ inches (12 cm.) wide and 16 inches (40 cm.) long. When stretched to 24 inches (60 cm.) it may be covered with a layer of potter's clay from 1 inch to $2\frac{3}{8}$ inches (25 to 60 mm.) thick, made as adher-

* As first shown by M. Alphonse Favre of Geneva (*La Nature*, 1878), from whom the accompanying cut — one of four in *La Nature*, — has been borrowed. See also *Nature*, xix, 103, 1878, and also Rev. O. Fisher: *Physics of the Earth's Crust*, 128. In this connection the reader should also refer to the passage previously quoted describing the cooling of a molten mass in the operations of a puddling furnace. See p. 219.

rent as possible to the India rubber, with a block of wood applied at each end. On the result shown in the annexed cut, several important observations may be made. (*a*) The strata are less contorted in the lower layers than in the upper. (*b*) The layers are disjoined in certain places by fissures or caverns. (*c*) They are traversed by clefts or faults inclined or vertical. (*d*) There is no sort of symmetry in these structures. (*e*) The lateral pressure was exerted only from two opposite directions, and not as in the case of the earth's crust, from all directions; and hence the folds reveal longitudinality or an axial dimension. (*f*) The corrugations are distributed over the whole surface, and not accumulated in "chains" or groups. The importance of some of these observations will appear hereafter.

The cooling and contraction which originate orographic wrinkles must be conceived as progressive and uniform. To a great extent, it may also be conceived, the evolution of mountain inequalities would be progressive and uniform. But a moment's consideration of the unequal constitution and rigidity of the rocks, and especially the unequal distribution of the firmest resistances to lateral pressure — especially after the primordial, fire-formed crust should have been once disturbed — renders it entirely probable that the progress of the development of surface inequalities would be somewhat spasmodic and convulsive. This theory, therefore, while recognizing an identity of forces and modes of action in ancient and later times, provides for any indications which may be discovered, of cataclysmic and revolutionary results of accumulated strains. It provides, also, for more energetic and more frequently recurring orographic activities in the earlier ages of the world than in the later. It also explains why later mountain up-lifts should exceed the earlier in altitude, since, owing to the increased thickness

and resistance of the crust, they could only have been produced after a longer continued and more highly intensified accumulation of strains. It is apparent, finally, that this theory, taken by itself, requires an immense number of comparatively short wrinkles running in every conceivable direction over the earth's surface, like the wrinkles in the skin of a shrivelled apple. The theory provides no cause for a tendency toward determinate directions and prolonged continuity in the wrinkles produced. But if mountains are developed from shrinkage wrinkles, we must explain, also, why they are disposed in ranges and chains of ranges, and why they tend to sustain certain uniform relations to the meridian. The general theory of these phenomena has been already explained in a previous part of this chapter, and its particular application to the earth will be considered in the next chapter, when treating rather of existing phenomena than of antecedent conditions.

The inauguration of a wrinkle would be the determination of lines of weakness, seen in cross section at *a*, *b*, *c*, Figure 51, parallel with each other. Evidently

FIG. 50.—ILLUSTRATING THE FORMATION OF MOUNTAIN WRINKLES.

any continued tendency to wrinkle would be most readily developed along the existing wrinkle, since the lateral pressure B G would be resolved at G into the two components G I and G F, the latter tending to develop an elevation at G. The component G I would be again resolved into I L and I *a*. The downward stress I L would be opposed by the underlying matter, which would contribute a part of its resistance along I *a*, and another part along I G. From the opposite direction, A, the lateral pressure would yield a component tending to depress *b*, and that, a component tending to elevate *a*. The two components meeting at *a*,

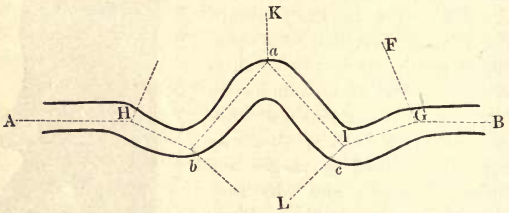

FIG. 51. FORMATION OF WRINKLES IN A PLANETARY CRUST WITH PARALLEL CONTIGUOUS FURROWS. CROSS SECTION.

would give a vertical or subvertical resultant *a* K. Thus, a wrinkle once inaugurated, further lateral pressure would tend to increase its elevation and deepen the parallel depressions. The weight and rigidity of the primitive fold *a*, finds always, ultimately, a component in the upward force G F, as explained, and this increases as the altitude and mass of *a* increase. In the course of time, therefore, accessory folds rise at G and H, separated from the main fold by the furrows *b* and *c*. In the later progress of these events the folds at G and H repeat the action of the fold *a*. Thus parallelism of mountain ranges would result, the lateral ranges of course diminishing consecutively with increase

of distance from the central fold, and at the same time broadening their bases.

The history of wrinkling must be regarded as beginning long before the descent of the ocean; but it continues through all the cooling æons of a planet's life. The ocean's waters would be accumulated to greatest depths in the deepest depressions between the wrinkles. When, after the measure of the oceans should be filled, the wrinkling should continue, the crests of the primordial wrinkles would be the first to emerge. Thus the germs of the continents, and afterward the continents themselves, would be stretched out in the places and in the attitudes predetermined before the ocean accumulated. The ocean basins and the ocean shores are conformed to the preconfiguration of the wrinkles. The location and trends of the mountain chains, therefore, have not been determined by the position of the ocean's mass, for the same cause has determined both. The ocean has pressed against the submerged slopes of the great folds, and to some extent has exerted an accessory lateral pressure. The effect of this, so far as it was felt, would be to increase the wrinkling effects and possibly (as Dana thinks) to incline the folds away from the coast line.

The error must be avoided of conceiving the wrinkled condition of the planetary crust as restricted to the land areas.* Wrinkles would necessarily exist along many meridians on all sides of the planet. The ocean at first would cover all; and only the highest folds and plateaux would ever emerge above the ocean level. There are

*Rev. O. Fisher assumes (*Physics of the Earth's Crust*, 169, 179, 282, 283) that surface plications have not been developed under the sea. And yet he refers in another place (*id.*, p. 78) to the fact that "contorted strata are to be also found, in what would be termed level countries, often covered with horizontal deposits of later date"—for example, the highly contorted, carboniferous strata of parts of Belgium; and we might add, the contorted Archæan of Canada and New York, overlaid by horizontal uncontorted Potsdam sandstone and succeeding formations.

mountains, valleys and plains in the bottom of the sea, as well as over the continents. The widest landscapes are buried beneath cubic miles of primitive brine.*

Professor James D. Dana, whose thoughts on all subjects are suggestive and weighty, has devoted to the theory of mountains more study, probably, than any other American geologist; and the whole subject of a shrinking globe and a wrinkling crust has been considered by him from every point of view.† Though his opinions in reference to a fluid nucleus and the great influence of the ocean, and probably also, on the subject of "mashing together" (something to be presently explained) have been modified by the progress of investigation, he has always maintained that "the principal mountain chains are portions of the earth's crust which have been pushed up and often crumpled or plicated by the lateral pressure resulting from the earth's contraction;" that the oceanic areas have been "the regions of greatest contraction and subsidence, and that their sides have pushed like the ends of an arch, against the borders of the continents," determining the border position of orographic and volcanic phenomena; that metamorphism has taken place only

*See the section from Charleston, S. C., across the Gulf Stream, by A. D. Bache, *Proc. Amer. Assoc.*, 1854, 141, and Diagram 9. But Bache's conclusions are not confirmed by Commander J. R. Bartlett, Bulletin No. 2, *Amer. Geograph. Soc.*, p. 73, 1882. For the general configuration of the Atlantic bottom, however, see C. Wyville Thompson: *Voyage of the Challenger; Depths of the Sea*, etc. On the configuration of the bottom of the Pacific, see J. D. Dana, *Rep. Geol. Wilkes U. S. Expl. Exped.*, 4to, 1849, p. 339, and *Corals and Coral Islands*, 8vo, 1872, p. 329.

†See a summary of Professor Dana's views in *Amer. Jour. Sci.*, III, v, 423–5, with references to numerous earlier publications by himself. The article here referred to is an extended memoir embracing his final conclusions *On some results of the Earth's Contraction from Cooling, including a discussion of the Origin of Mountains and the Nature of the Earth's Interior*, Part I, Review of opinions, and *Theory of Mountain Origin*, 423–43, June, 1873; Part II, *Condition of the Earth's Interior, and connection of Facts with Mountain-making*, and Part III, *Metamorphism*, *id.* III, vi, 6–14; Part IV, *Igneous Ejections*, vi, 104–6; Part V, *Formation of Continental Plateaux and Ocean Depressions*, vi, 161–72, Sep., 1873. See, also, Dana's *Manual of Geology*, 3d edition.

during periods of disturbance, and he now thinks that the heat required has been derived partly from the earth's liquid interior and partly from the crushing strains (see beyond) experienced by the crust. He maintains that wide areas have experienced geosynclinal and geanticlinal movements, and that the latter are not accompanied by plication and metamorphism, though they sometimes attain low mountain altitudes, and supplement the elevation of characteristically plicated and metamorphic mountain chains.

The theory of wrinkling over a molten interior, or even a fluid zone, has been objected to by Professor Joseph Le Conte* on the ground that the materials of the crust do not possess sufficient rigidity to sustain themselves much above or below the plane of fluid equilibrium. Hence the great folds of mountains and the broader arches of continents and plateaux, as well as the depressions of the ocean basins, cannot be regarded as the simple phenomena of wrinkling; and Professor Le Conte, like Archdeacon Pratt† and Robert Mallet,‡ refers these unequal saliences of the crust to unequal radial shrinkage. For some reason, as he thinks, the earth has contracted more along the radii under the depressions than along those under the elevations; and the earth has attained sufficient rigidity to sustain the pressure resulting from such inequalities.§ But great elevations and subsidences, and even mountain folds, are known to have been produced when the circumstances are such as to prove that the terrestrial crust

* *A Theory of the Formation of the Great Features of the Earth's Surface*, Amer. Jour. Sci., III, iv, 345, Nov., 1872.

† Pratt: *Figure of the Earth*, 4th ed., 200, 206, 1871.

‡ Mallet, *Trans. Roy. Soc.*, 1873, §§ 52, 60. Principal J. W. Dawson seems to entertain a similar view, as indicated in his Address in *Science*, ii, 197, Aug. 17, 1883.

§ Rev. O. Fisher, however, has shown that the whole radial contraction would not equal the difference of level between the land surface and the sea bottom.—*Physics of the Earth's Crust*, 79.

possesses sufficient rigidity to sustain the saliences, and sufficient hypogeal mobility to permit them sometimes to return to older positions. Thus, as Professor J. D. Dana has reminded us,* the region about Montreal and thence to Lake Champlain and the coast of Maine has been raised without evidence of plications from 200 to 500 feet in late Post-Tertiary time; and some of the higher regions of the Rocky Mountains have been raised 8,000 to 10,000 feet since the Cretaceous age, and there is no reason to suppose that any disturbances revealed in the Cretaceous and Tertiary strata have been the cause of the elevation. In other instances, as in the Alleghenies, the Uinta and the Sierra Nevada, as shown by Lesley, Powell and King, enormous downthrows have taken place, to the extent of 10,000 to 25,000 feet; and these are most naturally explicable on the theory of folds and arches in the earth's crust. In fact, it is a common thing to find a line of fault passing into a fold or flexures, as for instance, in the region of the High Plateaux of Colorado. It is scarcely conceivable that the flexure-continuation of a fault should not be sustained by its own strength over some mobile condition of matter ready to retreat as soon as the strain becomes too great for the material to withstand. The continuity of folds and faults is well illustrated in the experiment of Favre, previously described.

That folds and arches actually exist, and not merely elevations caused by crushing together, and that such folds or wrinkles would arise upon the surface of an incrusting globe is a conclusion so well sustained by facts and opinions that we may venture the assertion that the difficulty raised by Professor Le Conte is not a very serious one.

Captain C. E. Dutton has urged an objection which is more recondite. He questions the adequacy of contrac-

* Dana: *Results of the Earth's Contraction*, Amer. Jour. Sci., III, v, 428.

tion to develop the rugosities of the earth's crust. Starting from Fourier's solution of the problem of the "rate of variation of temperature from point to point, and the actual temperature at any point in a solid extending to infinity in all directions, on the supposition that at an initial epoch the temperature has had two different constant values on the two sides of a certain infinite plane," and using Sir William Thomson's application of the solution to the case of the earth, Captain Dutton finds that on any supposition as to present rate of increase of temperature downward, and as to the conductivity of the rocks, "the greatest possible contraction due to secular cooling is insufficient in amount to account for the phenomena attributed to it by the contractional hypothesis." "By far the larger portion of this contraction," he says, "must have taken place before the commencement of the Palæozoic age. By far the larger portion of the residue must have occurred before the beginning of the Tertiary; and yet the whole of this contraction would not be sufficient to account for the disturbances which have occurred since the close of the Cretaceous."

Captain Dutton thinks, also, that "the determination of plications to particular localities presents difficulties in the way of the contractional hypothesis which have been underrated." The localization of the plications is only possible on the assumption of a large amount of horizontal slipping of the crust over the nucleus, and this would present, even over a liquid nucleus, an amount of friction which renders the assumption a physical absurdity.* Wrinkling resulting from uniform cooling, and, consequently, uniform shrinkage, would be represented by the analogy of a withered apple, instead of a surface present-

*C. E. Dutton, *Amer. Jour. Sci.*, viii, 113-23, Aug., 1874. See also *Penn. Monthly*, May and June, 1870, on Theories of the Earth's Physical Evolution, and *Geol. Mag.*, Decade ii, Vol. iii, 327, reviewed in *Geol. Mag.*, iv, 322.

ing in one region one continuous system of plications extending from Cape Horn to Behring's Sea, and in another, a zone a thousand miles in width, from the Appalachians to the one hundredth meridian, with almost no evidences of disturbance presented.

Rev. O. Fisher has also made objection to the contractional theory.* While admitting that the crumpling of the earth's crust reveals the action of lateral pressure, he shows by calculation based on certain assumptions of constant quantities, that the elevations above a datum plane due to the contraction of a solid earth, would not form a layer exceeding nine hundred feet in thickness, while the actual elevations above the same plane would form a layer ten thousand feet in thickness. The compression, therefore, must be due to some other cause than contraction of the earth through loss of heat. He, therefore, attempts to establish the probability that the crust rests on a fluid zone in a state of igneo-aqueous fusion, and that the escape of steam and gases into fissures formed on the under side of the crust exerts the lateral pressure which has contorted the strata.

Captain Dutton's assumption that the contractional theory implies a molten nucleus enables him to argue that at the beginning of incrustation the whole earth had cooled nearly to the point of solidification. But, it may be held, as it is generally held, that the terrestrial nucleus began to

*O. Fisher: *Physics of the Earth's Crust*, ch. iv, London, 1881. Mr. Fisher's views on vulcanism and orogeny have mostly appeared in previous periodical publications. See, especially, *On the Elevation of Mountain Chains by Lateral Pressure*, Trans. Cambr. Phil. Soc., xi, Part II, 18; Part III, 489, 1868; *On Elevation and Subsidence*, Phil. Mag., 1872; *On the Formation of Mountains and the Hypothesis of a Liquid Substratum beneath the Earth's Crust*, Proc. Cambr. Phil. Soc., Feb. 22, 1875; *Mountain-making; The Inequalities of the Earth's Surface Viewed in Connection with Secular Cooling*, Trans. Cambr. Phil. Soc., xii, Part I, 505; Part II, 431, abstract in *Amer. Jour. Sci.*, III, x, 389–90; *Remarks upon Mr. Mallet's Theory of Volcanic Energy*, Quar. Jour. Geol. Soc., London, xxxi, 469–78, May 12, 1875; *Mr. Mallet's Theory of Volcanic Energy Tested*, Phil. Mag., IV, *i*, 302–19, Oct., 1875; *id.* V, *i*, 138–42.

solidify at a temperature much above the point of liquefaction under atmospheric pressure. If so, the process of equalization of temperature by convection could be carried on only in the region exterior to the consolidated nucleus, and when incrustation began, a very high temperature was shut up in the nucleus. A greater amount of cooling and contraction must therefore take place than would be possible on Captain Dutton's assumption of a liquid nucleus at a lower temperature. Moreover, Captain Dutton assumes, with Sir William Thomson, that as fast as surface materials solidified, they would sink by their increased density into the fluid mass, until the late-formed and comparatively cooled solid nucleus should have grown nearly to the surface. This would be an additional cause of general reduction of internal temperature. But the theory of a sinking crust can scarcely stand, in the light of recent researches, already cited, on the relative densities of freshly solidified masses, and the molten magmas from which they were derived. It is much more probable that incrustation began at an early stage, and at once began to arrest escape of internal heat, so that since the first incrustation, the interior has undergone a larger amount of shrinkage than Captain Dutton admits.* Still, it must be borne in mind that an initial temperature of 7000° Fahr. is assumed, and this is probably 3000° above the melting temperature of silicious rocks under atmospheric pressure. Undoubtedly, the results exhibited by Captain Dutton and Rev. Mr. Fisher respecting the inadequacy of all probable contraction through cooling, to develop the necessary tangential pressure, must be very carefully considered. But while the effects of contraction remain too clearly indicated to be mistaken, and while all admit, as they must, that some contraction must have resulted from cooling, it seems ra-

* Compare remarks by A. H. Green, *Nature*, xxv, 481, relative to the initial temperature of 7000°.

tional to maintain that the theoretical estimates of the results of possible contraction are vitiated by some undetected errors in the principles assumed or the constants employed.

As to Captain Dutton's objection that the formation of a mountain range is impossible upon a globe contracting equally along all its radii, this seems well taken, and I know of no way to meet it on principles generally recognized by geologists. As to myself, however, I am at once reminded of the tidal influences already discussed. Hereafter, in treating of the physiographic features of our planet, I shall point out the remarkable correspondences between the orographic trends and the structural lines which I believe must have been wrought by tidal action in the primitive crust. I strongly believe that in this is to be found the only explanation of the difficulty suggested.

As to the improbability of the requisite slipping of the crust to develop mountain ranges along certain meridians, with broad continental plains intervening, I am inclined to disagree with Captain Dutton. With an underlying liquid or plastic layer nearly or quite continuous, and meridional predispositions and lines of weakness preëxisting, it seems to me probable that regions of sound crust unaffected by any predisposition to folding, would possess sufficient rigidity to undergo the requisite local translation, and to press with the requisite force against rising folds, and even to press their bases under and cause their summits to overhang toward the continental side — a result exhibited remarkably in the Alps, where the pressure from both sides has been such as to develop overhanging in both directions from the centre, producing the well known fan-shaped structure. This is admirably seen in a section across Mont Blanc, where the Jurassic strata and underlying crystalline schists of Val Veni have been overturned toward the south, and the same formations in the valley of

Chamounix have been overturned toward the north, while the central protogine mass rests like a protruded bulge between the two sets of schists. Hard by in the Brévent, the crystalline schists have again been squeezed to a vertical attitude, but the protogine was not forced up in the middle. The contracted base of a great terrestrial fold is also seen in the St. Gotthard mass, included in the accompanying section through the Alps. The restored folds of this section, indicated by the dotted lines, convey irresistibly the impression of action from the sides. (See next page.)

The probability of crustal slipping is expressly recognized by Dr. Dawson, who, speaking of past movements of the earth's crust, says:* "One patent cause is the unequal settling of the crust toward the centre; but it is not so generally understood as it should be, that the greater settlement of the ocean bed has necessitated its pressure against the sides of the continents in the same manner that a huge ice-floe crushes a ship or a pier. The geological map of North America shows this at a glance, and impresses us with the fact that *large portions of the earth's crust have not only been folded, but pushed bodily back for great distances.*"

The pressure from the continental side of a fold should establish a relation between the height of a mountain-fold and the breadth of the continental area which has not been affected by the plications due to it, but which have been accumulated along its borders. In any event, the folds exist, and however caused, the same necessity of slipping over uncorrugated areas would arise.†

But finally, when we contemplate the physical situation

*J. W. Dawson, address at Minneapolis, as retiring president of the American Association, *Science*, August 17, 1883. Quoted only for the passage italicised, since the cause assigned would not tend to produce the effect alleged, but rather a wrinkling of the ocean bottom.

†The evidences of pressure from the continental side are recognized in the White Mountain region by C. H. Hitchcock (*Geol. of New Hampshire*, i, 519).

FIG. 52. SECTION THROUGH THE ALPS, SHOWING THE EFFECTS OF LATERAL PRESSURE.—From Heim's *Gebirgsbildung*. The line of the St. Gotthard Tunnel, and the plane of equal temperature, A B, beneath it, are compiled from F. Giordano, in *Bollettino del R. Comitato Geologico d'Italia*, Vol. XI., 1880, pp. 408-50.

in that "analytic spirit" which Captain Dutton recommends, it is apparent that the question of slipping does not properly arise. By hypothesis, the crust is underlaid by a liquid zone or a liquid nucleus. The shrinkage of the nucleus develops the lateral pressure in the crust; and the surface of the shrinking nucleus has all the motion here attributed to the crust, though less localized. The determination of the parts of the crust to yield to the pressure depends only on the location of the weakest regions. Points in the crust adjust themselves in position accordingly. If any friction arises between the crust and the underlying fluid, the fluid being free to move, moves with the crust, and the resistances offered to the adjustments resulting from relief from pressures of inconceivable magnitude are too inconsiderable to be mentioned in this connection.*

The expedient by which Mr. Fisher attempts to provide the requisite amount of tangential pressure in default of adequate contraction, is certainly original, if not a heavy strain upon credulity. Should the assumed state of igneo-aqueous fusion be granted, and should the existence of innumerable fissures be also granted, in a crust already so squeezed by contraction as to close every opening, it is still extremely difficult to admit that the penetration of the fissures by elastic vapors furnishes an adequate cause for mountain corrugations. As before stated, the utmost energy of confined vapors is insufficient to raise the mountains and crush the crust. Movements of elevation, moreover, have been slow, persisting through geologic æons; these are not the characteristics of the action of elastic vapors.†

*If Captain Dutton will turn to Baltzer's *Der Glärnisch ein Problem Alpinen Gebirgsbaues*, he will find a section which, under the interpretation given, demonstrates extensive slipping, not only over a liquid magma, but over older and consolidated formations; and not only slipping, but an amazing system of folds affecting, for instance, the Cretaceous and Eocene strata, without corresponding folds in the Jurassic and Triassic strata.

†Compare the criticisms of A. H. Green, *Nature*, xxv, 481, March 23, 1882.

The theory of lateral pressure through nuclear contraction is accepted in its general features by Professor Albert Heim of Zürich,* one of the most thorough and competent investigators of recent times. Heim, however, to the contractional theory adds a subsidiary hypothesis. He holds that the great pressure exerted on the deeper strata, say below 3,000 meters, reduces them to a plastic state. Thus, while the overlying more recent sediments attain and retain real rocky rigidity, the crystalline schists acquire a condition in which lateral pressure more readily develops folds and plications. Thus it often happens that movements of the crumpling deeper strata carry the rigid overlying strata by a slipping movement over considerable distances, until the accumulated strain results in a local fold of the newer and more rigid strata, as in the remarkable case of the Glärnisch section described by Baltzer. Dr. Friedrich Pfaff of Erlangen,† however, argues against the hypothesis of deep plasticity, maintaining that the deepest portions of the earth would, on this theory, be the most fluid, and the earth would thus be destitute of the rigidity demanded by astronomical conditions. He maintains further, that mountain phenomena are such as demand rigidity for the explanation of upheaval and folding, since plastic masses are shown by experiment to yield quite different phenomena, both when pressed and when exerting pressure.

Dr. Pfaff, after a careful examination of the contractional theory, concludes that it is inadequate to explain certain phenomena of mountain formation. His objections may be stated as follows: (1) Cooling would not necessarily produce the requisite contraction. If it should do so, there is implied (α) A temperature in the fluid in-

*Heim: *Untersuchungen über den Mechanismus der Gebirgsbildung*, 2 vols. A work embodying the results of long and tireless research.

†Pfaff: *Der Mechanismus der Gebirgsbildung*, 8vo., 143 pp., 1880.

terior much higher than the melting point of rock, and at the same time, (*b*) A cooling of the interior much more rapid than that of the surface. These two implications conflict, as he thinks, with each other. (2) The whole thickness of the crust must have suffered folding simultaneously, and this, in some cases, is not the fact, since the upper or lower formations have been separately folded. (3) The folds are localized instead of being generally distributed over the surface. (4) The folds extend in long ranges of determinate direction, instead of being promiscuously disposed. (5) The newer formations have received more extensive folds than the older, whereas progressive cooling should result in progressively diminishing contractional results. The second, third and fourth objections are considered the most serious.

As to Dr. Pfaff's first objection, I think it loses its force in view of general considerations heretofore presented. As to the second, we may admit that the whole crust would be subjected to similar action, but we might reasonably expect the visible results to be differently developed in formations of different constitution and rigidity, and acted on by different superincumbent pressures. Deep-seated plasticity, for instance, as Heim suggests, may be reasonably conceived a true explanation of discordant movements in the upper and the deeper portions of the crust; though the plasticity supposed need not be attributed solely to pressure, but partly to the effect of heat and water in a zone more shallow than that where compression results in solidification. As to the third and fourth objections, they will be recognized as identical with certain ones urged by Captain Dutton, and their removal results, as I have shown, from the recognition of the effects of tidal action on an incrusting planet. As to the fifth objection, it seems to assume that the newer formations have been more disturbed because they have been

wrought into larger folds. There is no other evidence. But the premises of the objection probably invert the facts. The older strata have been most disturbed. But in the earlier and thinner condition of the crust, lateral pressure developed more numerous plications and a greater amount of crushing; in the later condition, increased rigidity resisted pressure until the strain accumulated to such an extent as to evolve movements more extensive vertically, though much less numerous.

Dr. Pfaff, however, chooses, for the present, to set aside the contractional theory, and in its place offers the hypothesis that large quantities of water finding their way into the crust, by some means which he does not explain * excavate vast cavities, and that the subsidence of the overlying strata gives rise to the dislocations which thus affect the upper and not the deeper portions of the crust. It does not seem to occur to Dr. Pfaff that this hypothesis involves greater difficulties than the theory for which it is proposed as a substitute.

The theory of mountain origin through wrinkling of the crust may suffice to explain elevation, volcanic and seismic actions, and even metamorphism and plications; but there are two characteristics of mountain corrugations which this theory cannot explain. These are the great *thickening* of the formations involved in the corrugations, and the greatly increased *fragmental* condition of the sediments. To supply these deficiences in orogenic theory other speculations have been promulgated, which I will now concisely explain.

3. *Theory of Copious Sedimentation along Geosynclinals.*—In 1857, Professor James Hall, in a presidential address before the American Association at Montreal, enunciated the doctrine that the enormous thickening of

* "Wir sind bis jetzt allerdings nicht im Stande, darüber genaue Auskunft zu geben, wir Wissen nur, das wasser in die grössten Tiefen hinabdringt, aber nichts Sicheres über seine Wirkung daselbst."—*Op. cit.*, 119.

the formations along the Appalachian chain was due to the prolonged accumulation of sediments along a sinking, off-shore line of sea-bottom. The study of the Appalachians and other American mountain regions led him to the enunciation of a general theory, of which the principal points are the following: Coast regions are the courses of marine currents, and hence of deposited sediments. The accumulation of sediments by their gravity gradually sinks the crust, and thus a great thickness is attained; the rocks become solidified and crystallized below. The continents are afterward somehow raised — not the mountain regions separately. The mountains are shaped out of other sediments by denudation — as James Hutton had previously argued. Metamorphism is due to "motion," "fermentation" and a little heat — the last coming up from below in consequence of the increasing accumulations at the surface.* A summary of these views, and to some extent, a commentary on them, was published by Dr. T. S. Hunt, in 1858.† Dr. Hunt entertains generally the same views as Professor Hall, and indeed preceded him in the conception of a softened plastic zone in a state of igneo-aqueous fusion, situated between the consolidated crust and the solid nucleus; though he was also preceded in this by Keferstein‡ and Sir John Herschel.§ Dr. Hunt places greater stress than Professor Hall on the influence

* Prof. Hall's address is published only in the *Introduction* to vol. iii, Palæontology of New York. [By a resolution of the Standing Committee of the Association, in August, 1882, the address is to be published by the Association, after an interval of twenty-five years.] See criticisms by J. D. Dana, *Amer. Jour. Sci.*, II, xlii, 205–11.

† T. S. Hunt, *Canadian Journal*, March 7, 1858; *Quar. Jour. Geol. Sci.*, Nov., 1859; *Amer. Jour. Sci.*, II, xxxi, 411. See, also, correlated views in *Amer. Jour. Sci.*, II, l, 21, and *Geol. Mag.*, June, 1869, on *The Probable Seat of Volcanic Action;* also, *Amer. Jour. Sci.*, III, v, 264–70. Prof. Hall's theory is in part accepted by Geo. L. Vose in *Orographic Geology*, 1866, 47–55, 134.

‡ Keferstein: *Naturgeschichte des Erdkörpers*, 1834, vol. i, 109; *Bull. Soc. géolog. de France*, I, viii, 191.

§ Sir John Herschel, *Proc. Geol. Soc., London*, 1836, ii, 548; Babbage's *Ninth Bridgewater Treatise*, Note I, 225–57.

of softening. He conceives the most important result of the subsidence to be, to "cause the bottom strata to establish lines of weakness or of least resistance in the earth's crust, and thus determine the contraction which results from the cooling of the globe to exhibit itself in those regions, and along those lines where the ocean's bed is subsiding beneath the accumulated sediments." While Professor Hall had conceived the process of subsidence as the principal *cause* of the corrugations of the strata, Dr. Hunt regarded the subsidence rather as the occasion which determined the position and direction of the corrugations, while the cause of the displacements and metamorphism was the contraction of the earth's nucleus, and of the deep-seated sediments themselves.

Professor Joseph Le Conte has entertained a similar view* as to the cause of subsidence. "Suppose," he says, "sediments accumulating along the shores of a continent, the first effect is lithification, and therefore, increasing density, and therefore, contraction and subsidence, *pari passu* with the deposit. Next, if the sedimentation continues, follows aqueo-igneous softening, or even melting, not only of the lower portion of the sediments themselves, *but of the underlying strata upon which they were deposited.* The subsidence probably continues during this process. Finally, this softening *determines a line of yielding to horizontal pressure*, and a consequent upswelling of the line into a chain. Thus are accounted for, first, the subsidence, then the subsequent upheaval, and also the metamorphism of the lower strata so universal in great mountain chains" (p. 468).† Professor J. D. Dana attributes the subsidence chiefly, at least, to lateral pres-

*J. Le Conte, *A Theory of the Formation of the Great Features of the Earth's Surface*, Amer. Jour. Sci., III, iv, 345-55, 460-72, Nov. and Dec., 1872.

†Subsidence under weight of sediments is recognized by J. S. Gardner and Dr. Charles Ricketts in communications to the Geological Section of the British Association in 1882.—*Nature*, xxvi, 468, 469, Sept. 7, 1882. See, also, note p. 334.

sure. He holds distinctly, also, to a real local elevation of the crust along a mountain geosynclinal, at the end of the subsidence, attended by plication and metamorphism. He holds also, that real elevations occur sometimes without plication and metamorphism.*

This theory offers a probable explanation of the augmented thickness of mountain formations,† but physical geologists will scarcely indorse the presumption that the formation of a geosynclinal is due to an accumulation of sediments. It is indeed, frequently asserted that delta regions are generally in process of subsidence under the weight of deposits; but it is scarcely credible that a crust possessing sufficient rigidity to sustain the weight of mountains, would be subject to depression under the load of a few feet of sediments buoyed up by immersion in the sea‡. Moreover, Mr. Clarence King has shown§ that subsidence has in some cases accompanied unloading of sediments, and the accumulation of sediments has been attended by upheaval. The theory apparently inverts the relative positions of cause and effect.‖ If, however, subsidence from nuclear contraction or any other cause is taking place along a shore, this depression will naturally determine the place of excessive accumulation of sediments, especially if an ocean current corresponds in position and direction.

* Dana, *Results of the Earth's Contraction*, Amer. Jour. Sci., III, v, 423 43, June, 1873, continued, ib., vi, 6–14, 104–6, 161–72.

† Prof. J. D. Whitney ascribes the thickening of the formations reposing along the flanks of a granite axis to the denudation of this axis after upheaval in the midst of the ocean. (J. D. Whitney: *Mountain Building*. Also, *North American Review*, cxiii, 235–74.) How high must the axis have been to supply the requisite amount of sediments in any average case?

‡ Compare Fisher, *Geographical Magazine*, x, 248.

§ King: *Geology of the 40th Parallel*, i, 357, 732.

‖ Nevertheless M. Faye attributes even greater effects to accumulation of burdens upon the ocean's bottom. This depression of the sea-bottom is reciprocated, he thinks, by the elevation of continents and mountain chains. To the weight of sediments, however is added, on his theory, the effect of increased thickening of the cooled crust under the ocean.—*Faye, Annuaire du Bureau des Longitudes*, 1881.

This theory also explains the coarsely fragmental character of the deposits, especially if the depression is overflowed by an ocean current bringing sediments from a crumbling coast, as was suggested by Professor Hall, who posited a wasting continent to the northeast of the Appalachian geosynclinal.

The theory is unsatisfactory, however, on two additional points. Perhaps it should be said the theory is incomplete. It does not offer an adequate explanation of mountain saliences. That some mountains are strictly results of neighboring erosions cannot be doubted. Nor is it easier to doubt that others have originated through some sort of local elevation. Very few American or European mountains indicate by their structure that they are mere remnants of wasted continents. The dips of the strata flanking them almost universally demonstrate that uplifts have taken place which have inclined the sheets of sediments along each side. Nor does the theory offer an adequate explanation of the enormous amount of plication and crumpling which generally accompany mountain forms. It seems to conceive the synclinal trough filled by sediments to a state of convexity and so maintained while slowly sinking. The sinking process effects the plication. Now the plication, in many cases, amounts to at least twice the horizontal extent of the formation, and this would require in a synclinal twenty-five miles wide, a vertical altitude of fifty miles. In any ordinary case of crumpling or plication, the altitude must have been equal to the breadth of the synclinal, or so nearly equal to it as to annihilate all presumption in favor of the theory. Dr. Hunt joins to this action the secular contraction of the earth's nucleus, and Professor J. Le Conte, Professor J. D. Dana and others assign secular contraction alone as the cause of plications along a filling geosynclinal. The latter two also main-

tain that the plications were produced chiefly at the end of the process of subsidence.

4. *Theory of Mashing Together.*—In 1872, Mr. Robert Mallet, an eminent English engineer, propounded* the theory that the secular contraction of the earth's nucleus had developed tensions in the crust, which found relief in the local crushing of the rocks along lines of relative weakness, and thus heat was evolved by transformation of mechanical energy. Mr. Mallet, however, maintained that in the earlier condition of the earth, while the crust was thinner, tangential thrust had developed mountain folds, whereas, in modern times, it develops chiefly vulcanic and seismic phenomena. He substantiated his theory by a citation of many results of the experimental crushing of rock fragments, and calculated that the total heat escaping through volcanic vents is fully accounted for by the thermal effects of the secular crushing of the crust, while the normal radiation is supplied by slow conduction from the primitively heated interior. Mr. Mallet subsequently enforced these views by many observations, experiments and calculations.†

* Mallet, *Volcanic Energy, an Attempt to Develop its True Origin and Cosmical Relations*, Proc. Roy. Soc., No. 136, 1872, Phil. Trans., 1873, pt. i, 147, abstract in *Amer. Jour. Sci.*, III, iv, 409-13; vii, 145-8; additions to this, *Phil. Trans.*, 1875, clxv, pt. i, abstract in *Amer. Jour. Sci.*, III, viii, 140-1. For criticisms and comments on Mallet's theory see Sir William Thomson, *Nature*, Jan. 18 and Feb. 1, 1872 (compared with which see J. G. Barnard, *Smithsonian Contributions*, No. 240, and Sir W. Thomson's later publications, with modified views); D. Forbes, *Nature*, Feb. 6, 1872; F. W. Hutton, *Nature*, Nov. 27, 1873; E. W. Hilgard, *Amer. Jour. Sci.*, III, vii, 535-46, June, 1874, and *Phil. Mag.*, July, 1874, 41.

† Robert Mallet, *On the Temperature Attainable by Rock-crushing, and its Consequences*, Phil. Mag., July, 1875, 1-13, and *Amer. Jour. Sci.*, III, x, 256-68, xii, 463; *Phil. Mag.*, V, i, 19-22. See, also, Mr. Mallet's *Introduction* to L. Palmieri's work on the *Eruption of Vesuvius in 1872*, entitled, *On the Present State of Knowledge of Terrestrial Vulcanicity, the Cosmical Nature and Relations of Volcanoes and Earthquakes*, abstract in *Amer. Jour. Sci.*, III, v, 219-25. Numerous other publications by Mr. Mallet bearing more particularly on the science of volcanoes and earthquakes may be found in *Trans. Roy. Irish Acad.*, 1848; *Reports to British Assoc.*, 1850, 1851, 1852, 1853, 1854, and *Trans. Brit. Assoc*, 1857-8; *The Great Neapolitan Earthquake of 1857*, 8vo, 1862, pt. iii; *Phil. Trans.*, 1862, and *Amer. Jour. Sci.*, III, v, 302.

It ought to be mentioned that Professor Wurtz, as early as 1866, advanced kindred ideas.* He referred to "the tremendous dynamic agencies whose effects of upheaval, subsidence, disruption and displacement we find so widely manifest. [These] while doubtless themselves engendered of the pent-up heat-energy of the interior, must have given birth to, or have been in part transmuted into, heat-motion. Hence I deduce two conclusions of great moment, but one or two of which can now be dwelt upon. It follows, for instance, that in our theoretical views of metamorphism, we are by no means of necessity limited for our essential chemical excitant, merely to that portion of the hypothecated residual cosmical heat which might be supposed to have been retained by the emerging ocean floor. Neither elevation nor subsidence (both necessarily accompanied by enormous compression) could occur without rise of temperature." * * * In a note he inquires, "whether the general rise of heat represented as found on descent into European mines, may not possibly admit of a similar explanation."

Almost simultaneously, a similar conception was put forth by Mr. George L. Vose.† "The enormous pressure," he says, "generated in the folding of masses of rocks the depth of which is measured by miles," must result in great mechanical and chemical changes. But Wurtz and Vose merely made suggestions.

Quite independently of Mallet's reasoning and apparently, also, of the inconspicuous suggestions of Wurtz and Vose (though both are mentioned), Professor Joseph Le

*In a paper read before the American Association at its Buffalo meeting, and afterward published in the *Amer. Jour. of Mining*, Jan. 25, 1868. See extract in *Amer. Jour. Sci.*, III, v, 385–6.

†Vose: *Orographic Geology, or the Origin of Mountains.* A Review. Boston, 1866. 8vo. 136 pp.

Conte, of California, arrived at very similar conclusions,* and like Mallet presented them with adequate exposition. He, however, combined with them Hall's conception of copious deposition along a sinking sea-bottom. He went beyond Hall, at the same time, in maintaining a local elevation of the subsided belt, though this was viewed simply as the consequence of extensive mashing together, and not of folding. "According to my view," he says, "this yielding [to tangential thrust] is not by upbending into an arch, leaving a hollow space beneath, nor such an arch filled and supported by an interior liquid, but a *mashing or crushing together horizontally, like dough or plastic clay, with foldings of the strata, and an upswelling and thickening of the whole squeezed mass.*" According to Professor Le Conte's views, previously explained, the "upswelling" must be accompanied by a still greater downswelling to counterpoise the elevation. This view is also maintained by Rev. O. Fisher, who says: "The peculiar arrangement which is requisite for the equilibrium of a disturbed crust resting upon a heavier fluid substratum is, that for every subaërial elevation above the mean surface there must be a corresponding protuberance dipping downwards into the fluid below; and, according to the relative densities which we have assumed, the depth of these protuberances must be about ten times the height of the elevations."† The writer proceeds to state that this deep protuberance would explain the relative feeble action of mountains on the pendulum, since the mountain and its "roots" would be less dense than the fluid in which they

*J. Le Conte, *A Theory of the Formation of the Great Features of the Earth's Surface*, Amer. Jour. Sci , III, lv, 345 and 460, Nov. and Dec., 1872. Supplementary Note, v, 156. See T. S. Hunt's Criticisms in *id.*, v. 264–70, and Le Conte's Reply in *id.*, v, 448, June, 1873. See J. D. Dana's remarks in *id.*, v, 26–8.

†Fisher: *Physics of the Earth's Crust*, 286. Prof. James Hall had previously said of mountains, "There is doubtless as much of the mass below the level of the sea as above it."—*Pal. New York*, iii, *Introduction.*

float; but he states elsewhere that "the downward protuberances of the crust into the fluid substratum, which we have termed the roots of the mountains, will be gradually melted," and in this he is unquestionably correct. This must cause the mountain gradually to subside to the common level, or the elevation must be sustained arch-like, with the creation of strains in the contiguous crust. But as the mountains have not subsided, they must, therefore, consist of elevations without "roots," and these elevated masses of matter, so far below the melting temperature, must be *denser* than the underlying fluid. Hence they should exert an *excess* of attraction on the pendulum, instead of a deficiency. It seems more probable that the elevations are sustained partly by flotation, and partly by lateral resistances of the crust, and that the *lighter* liquid fills a portion of the arch, giving the mountain a mean density less than if it were completely solid and cold.

The final crushing together of a geosynclinal, forming a mountain protuberance, constitutes what Professor Dana has styled a "synclinorium." "In such a process of formation," he says, "elevation by direct uplift of the underlying crust has no necessary place. The attending plications may make elevations on a vast scale, and so also may the shoves upward along the lines of fracture, and crushing may sometimes add to the effect; but elevation from an upward movement of the downward bent crust is only an incidental concomitant, if it occur at all."*

In connection with the effects of crushing pressure, it is interesting to recall the older views of Sir Charles Lyell: "To assume that any set of strata with which we are acquainted are made up of such cohesive and unyielding materials as to be able to resist a power of such stupendous energy [as that which uplifted the coast of Chili, in 1822 and 1835] if its direction, instead of being

* Dana, *Amer. Journal of Science*, III, v, 431.

vertical, happened to be oblique or horizontal, would be extremely rash. But, if they could yield to a sideway thrust, even in a slight degree, they would become squeezed and folded to any amount, if subjected for a sufficient number of times to the repeated action of the same force. * * * Among the causes of lateral pressure, the expansion by heat of large masses of solid stone intervening between others which have a different degree of expansibility, or which happen not to have their temperature raised at the same time, may play an important part. But as we know that rocks have so often sunk down thousands of feet below their original level, we can hardly doubt that much of the bending of pliant strata, and the packing of the same into smaller spaces, have frequently been occasioned by subsidence." *

5. *Statement of separate Constructive Conceptions relative to Mountain-making.*—Having presented a concise outline of the principal theoretical systems of mountain-making, we may glance back and eliminate the distinct conceptions which have risen into notice from time to time, and most of which have some valid grounds for recognition, and have contributed something to the final theory. They may be enumerated as follows:

(*a*) A liquid nucleus and comparatively thin crust.
Explains internal heat, and instability of earth's surface.
Objections. Astronomical, based on precession, nutation, tides, moon's secular acceleration; also support of mountain chains. [Probably mostly good.]

(*b*) A solid nucleus and a plastic zone, either continuous (Fisher) or interrupted (W. Hopkins).
Explains terrestrial rigidity; also, in part, volcanic and seismic phenomena.

* Sir C. Lyell: *Principles of Geology*, 8th ed., 1850, pp. 167–8. The mashing process is recognized by Prof. C. H. Hitchcock in his discussion of the White Mountains (*Geology of New Hampshire*, i, 518–22, 1874). He also finds strata crumpled in detail and not in the mass and all alike, as represented by Rogers (*id.*, ii, 114, 1877).

(*c*) Action of elastic vapors beneath the crust.

Explains volcanic and seismic phenomena.

Objection. Inadequate for mountain formation and maintenance. [Good.]

(*d*) Secular contraction of the earth more rapid in the nucleus, thus causing stresses in the crust (C. Prévost).

(*e*) The stresses of the crust find relief in wrinkles and plications.

Explains elevations, anticlinals and synclinals with or without plications.

Objections. (*aa*) Contraction insufficient (Dutton, Fisher). [To be considered.] (*bb*) The wrinkles would not serve as germs of elongated mountain ranges (Dutton). [Good.]

(*f*) The stresses of the crust find relief in mashing together.

Explains heat and metamorphism (Wurtz, Mallet) as well as plications (Le Conte).

Objections. (*aa*) Would not develop sufficient heat (Dutton). [To be considered.] (*bb*) The heat would not be sufficiently localized (Dutton, Fisher). [Not good.]

(*g*) The mashing together sometimes results in mountain-like upswellings which have still greater down-swellings to counterpoise them (Le Conte, Fisher).

Explains the equilibrium as in an assumed state of flotation, and relieves the crust of strains derived from their weight (if that be necessary).

Objections. (*aa*) The downward protuberances would be melted off. [Good.] (*bb*) The crust can stand the strain. [Good.] (*cc*) Pendulum phenomena show the mountains deficient in mass or density. [Good.]

(*h*) A residue of the primitive heat remains in the earth.

Explains internal heat and accompanying effects.

(*i*) Ascent of isogeothermal planes as a consequence of sedimentation (Babbage, Herschel).

Explains metamorphism of sediments.

Objection. Does not explain metamorphism in strata overlying strata not metamorphic. [Good.]

(*j*) Excessive sedimentation along geosynclinals — these being either the effects (Hall) or the cause (Le Conte) of the excess of sedimentation.

Explains (*aa*) deep seated metamorphism; (*bb*) great thickness and fragmental character of mountain formations.

Objection. Insufficient, as giving no explanation of the longi-

tudinal extension of geosynclinals or of the causes which may produce them (ocean currents or nuclear contraction). [Good.]

(*k*) Igneous and perhaps aqueo-igneous softening along a deep geosynclinal.

Explains (*aa*) existence and direction of a line of weakness; (*bb*) Local metamorphism and vulcanism.

(*l*) Contraction under ocean basins developing results more especially along continental shores (Dana).

Explains the border location of mountain chains and volcanoes.

Objection. The ocean bottoms seem to have been also the seat of development of contractional results. [Good.]

(*m*) Weight of ocean would add something to landward pressure resulting from (*l*).

(*n*) Contractions under extensive plains developing results along border chains of mountains.

Explains (*aa*) absence of plications from extensive land areas; (*bb*) The border location of mountain chains.

Objection to (*m*) and (*n*). The crust would not slip, even if resting on a liquid (Dutton). [Not good.]

(*o*) Union of superheated steam with a zone of matter beneath the crust, forming a state of igneo-aqueous fusion (Fisher).

Explains lateral pressure (as the author of it thinks) to supply alleged deficiency of contractional tension.

Objections. Energy insufficient; action too local and too little persistent. [Good.]

(*p*) Tidal action on the primitive forming crust, as determinative of lines of submeridional structure in the crust. (See this work, Part II, Ch. ii, § 6, 4.)

Explains (*aa*) existence of elongated geosynclinals; (*bb*) Their submeridional direction — both otherwise entirely unexplained; (*cc*) The determination of the oceanic circulation in definite submeridional currents, should these be appealed to as cause of submeridional sedimentation and subsidence.

(*q*) Tidal action on the modern earth as a tributary cause of vulcanism and seismic phenomena — acting (*aa*) By the production of crushing stresses; (*bb*) By the partial relief of pressure in places, and consequent fusion (King). (See this work, Part II, Ch. ii, § 6, 6.)

Explains relations of these phenomena to lunar and solar positions.

6. *Final Conception of Orogenic History.*— This series of results, worked out by many minds, probably supplies all the principal elements of a final theory. I shall, therefore, undertake to furnish the reader with a concise digest of orogenic history, framed of those conceptions which seem best to comport with observed facts, and with the operations of physical forces.

While the molten earth was growing through the precipitation of mineral rains, consolidation began at the centre. The heat of the solid nucleus was exceedingly intense, and could escape only by conduction to the enveloping fluid, and thence by convection to the terrestrial surface. When superficial incrustation began, the *fluid* portion of the earth had fallen nearly to the temperature of solidification. The forming crust having a temperature little below that of the underlying liquid, its density was less, and it floated on the liquid magma; though later, when its mean density somewhat exceeded that of the magma, its own rigidity may have contributed something to its support. At this stage the moon probably was much nearer the earth than at present, and the tidal action was intense. While in the formative stage, the crust was impressed by systems of submeridional structure, as a consequence of the tidal lagging which gave the tidal force of the moon an effective tangential component. In this action was implanted that bias toward meridionality which has revealed itself in all the great primitive features of the earth's crust. As a consequence of this, when nuclear contraction became operative in the wrinkling of the crust, the wrinkles became elongated and meridional; and the contractional results transverse to these produced only rugæ and knobs in the main wrinkles, or at most, short transverse plications. Probably, to some extent also, the tendency to latitudinal wrinkling was transformed, over plains, by displacement of parts, into movements conform-

able with the fundamental and predetermined system of wrinkles. This is the only solution of a difficulty which Captain Dutton has shrewdly urged against the contractional theory; and the solution seems satisfactory.

The first ocean spread itself universally over the wrinkling crust. There were ridges and valleys beneath the sea. The thickening of the crust experienced an acceleration. Copious chemical precipitates were thrown down, and mechanical detritus was mingled and interstratified with the precipitates. The atmosphere had yielded something to the gathering sediments, so that the crust received more than it gave. At a later stage the contraction of the nucleus enlarged the wrinkles, and the inequalities of the sea bottom resulted in partial emergences. Simple synclinals were now combining into geosynclinals. The emergent crust was powerfully eroded, and the sediments gathered along the deeper synclinals and geosynclinals, more especially if these were located near the origin of the sediments. Meanwhile the nuclear contraction continued to depress the geosynclinals and elevate the geanticlinals. If water, confined beneath the crust, was capable of uniting with the molten mass, its progressive escape should have supplemented the possibly insufficient results of simple nuclear cooling. With accession of sedimentary layers to the upper surface of the crust, corresponding thicknesses were melted from the under surface, except so far as progressive cooling of the earth, or diminished conductivity of the crust permitted a permanent thickening of the crust. Thus, step by step, with the emergence of the geanticlinals, proceeded the depression of the geosynclinals, and the filling of certain of them with sediments. The excess of sedimentation along the geosynclinals caused these regions to experience most the melting and softening action of the heat beneath. By degrees some of the geosynclinals became composed

of softened sediments below, and fresh and imperfectly consolidated sediments above, while the main expanses of the crust were composed of older and more rigid materials. This was especially true of the geanticlinals. The geosynclinals were therefore zones of weakness in the crust. With continued nuclear shrinkage, the geosynclinals continued to sink and the geanticlinals to rise, until at length the lateral thrust of a geanticlinal mass became too great for one of the contiguous geosynclinals to bear. The geosynclinal refused to be further depressed. The plastic mass yielded by collapse. The result was an enormous amount of crumpling, plication and crushing of the softened strata, with the development of additional heat and the formation of faults and slides, and some shoving and over-slipping. These effects would be greatest along the axis of the geosynclinal. While the geanticlinal subsided to some extent, the geosynclinal was levelled up to the sea surface, or even hundreds or thousands of feet above it. The synclinorium was now complete. There was undoubtedly some, perhaps great, simultaneous downward swelling beneath the crumpling geosynclinal, but while the emerged protuberance was becoming cold and rigid, the submerged protuberance gradually disappeared. Subsequent subaerial erosions reduced the elevated range to the condition in which mountains present themselves to human observation, while meantime the wasting material was transported into other geosynclinals whose crises had not yet been reached.

It must be confessed that the elevation of the depressed geosynclinal into a protuberance of mountain magnitude presents some mechanical difficulties which may need to be further considered. Is the simple work of crumpling, mashing and plication a sufficient explanation of the anticlinal structure, and often enormous elevation, which belong to mountain phenomena? M. Faye has considered

the influence of the ocean's bottom temperature upon the thickness of the suboceanic crust, and he argues that the subsidence of the thickened ocean floor would react beneath the continental areas, and produce all the phenomena ascribable to upheaval. The doctrine of wrinkling by lateral pressure, he dismisses entirely. Now it can be readily admitted that such subsidence of ocean bottoms, additionally loaded by the weight of ocean waters, would result. A part of the subsidence would be compensated by refusion on the under surface, as before explained, and a residual part would exert a mechanical pressure which would react under the land. But the reaction would be generally distributed. It might thus tend to upraise broad continental surfaces, and force lava through the weak places of the crust. But the greater problem in geological mechanics is to explain the special and local elevatory phenomena seen in mountains, and especially the great and numerous folds which have come into existence in the principal mountain chains. It is possible that the great and constant pressure exerted by the thickened ocean bottoms upon the fluid understratum may determine a constant tendency of other parts of the crust to rise, and thus contribute something to the mechanical agencies which produce mountainous elevations on occasion of the collapse of a loaded and softened geosynclinal.

The synclinorium was now more an arch than a geosynclinal. While, therefore, nucleal contraction continued through later ages, the synclinorium presented a form which invited further uplifts. It became, in some cases, a true geanticlinal undergoing supplementary uplifts from age to age, or sometimes sinking as some neighboring geosynclinal attained its crisis

Thus the crests of mountain ranges are lines of fracture, and often of prolonged structural weakness. In all cases, excessive erosion has thinned and weakened the rocky

covering of the plastic magma which rises into the mountain form — not, indeed, to a point above the general level of the continent, but to a point quite above the general level of the under side of the crust — but more especially beneath chains of mountains covering elevated regions of great breadth, as the Rocky Mountains and the Himalayan plateau, * and, as shown to some extent, in the section across the Alps, Figure 52. At the same time, the actual thickness of the solid material may be greater in mountains than beneath extensive plains, in consequence of the increased amount of radiating surface. Yet, in case of reactions of the underlying molten matter against the crust, in consequence of local subsidence somewhere, or even the general gravitative pressure of the crust, or some motion resulting from tidal action, it must be that easiest vent, save in case of linear fractures, would be found along the crests of mountain ranges. On this reasoning, the highest ranges would be most likely to offer easiest relief. So volcanic vents should be expected at mountain summits as well as along lines of fracture in the level crust. At the same time, it is not contended, against the view of Mr. Poulett Scrope, that very many — mostly moderate-sized — volcanic mountains are not wholly formed from erupted matters.

In this view, the location of a progressing geosynclinal and its synclinorian outcome is not determined by the ocean. The geosynclinal is an incident of the general diversification of the earth's surface contour, and the synclinorian outcome depends on the proximity of a source

*This conception is anticipated by Archdeacon Pratt. "It is possible," he says, "that the superabundant matter in mountain regions having been heaved up from below, or at any rate, having been left aloft as the earth contracted its volume, there may be a deficiency of matter below the mountains, which would, under certain circumstances, have the tendency of counteracting their effect on the plumb line." — Pratt: *The Figure of the Earth*, 4th ed., 87. Compare also Airy, *Phil. Trans.*, 1855; Pratt, *Phil. Trans.*, 1858–9, and the results of Schmeizer's observations, in *Monthly Notices Ast. Soc.*, April, 1862.

of sediments. Remote from shores, geosynclinals are in progress beneath the sea, which will never attain synclinorian crises, unless some revolution provides supplies of sediments. The weight of the ocean, nevertheless, must have contributed something to the tangential thrust which increased the elevation of a synclinorium after it acquired the relations of a geanticlinal. This, however, it seems to me, must, in some cases, have been exceeded by the tangential thrust transmitted from a broad continental space not undergoing plication, and especially such a space already raised into a geanticlinal. The inclination of synclinorian folds toward the continent would result rather from the continental than from the oceanic thrust.

Similarly, the border situation of volcanic ranges is not due to oceanic action, since the shore-line and the volcanic range have been determined simultaneously by the position of a completed synclinorium. The ocean being in proximity to the volcano, its water naturally finds access to the media destined to be ejected, and even aids in their ejection; but it is an error to suppose that elastic vapors are capable of doing the greater work of volcanic and seismic activity.

The progress of the geosynclinal would be attended by the slow metamorphism of the deep sediments, through the agency of internal heat and water. The synclinorian crisis would produce plications and elevations, together with additional heat and further metamorphism. The completion of the synclinorium would be followed by completed crystallization and consolidation. Later geanticlinal action would bring the mountain chain to its maximum elevation. In still later periods, this elevation would be reduced by erosion and by subsidence resulting from strains in the contiguous crust, due to the weight of the mountain-mass.

7. *Analytical Conspectus of Orogenic Speculations.*—

To render as clear as possible to the general reader the relations of the various theories of mountain-making which have been passed in review, I introduce here an analytical exhibit in which the different orogenic conceptions are ranged in due order of subordination; and some effort is made to annex to the several characteristic conceptions of different investigators the views which they have associated in their systems with the conceptions contributed by themselves.

I. Reaction of heated elastic vapors beneath the crust.
  The vapors generated from matter admitted from above,
    With a thin terrestrial crust, ... Davy, etc.
    With a solid earth and local lakes of lava, . . . Hopkins.
  The vapors generated beneath the crust in a liquid or plastic zone, and causing, in fissures, lateral compression, crushing and plications, ... Fisher.
II. Expansion (by heat) of subsided sediments, . . . Babbage.
III. Depression of thickened crust beneath oceans, and reaction on continents, ... Faye.
IV. Contractional mechanism (C. Prévost, E. de Beaumont, Sedgwick, etc.).
  Meridionality unexplained.
    Fluidity primitive.
      The earth's nucleus fluid (Humboldt, v. Buch, etc.), ... Old Theory.
      Fluidity or plasticity limited to a zone more or less continuous,
        Without intervention of geosynclinals, and without mashing together. Wrinkling alone.
          Plications the accompaniment of general contraction, ... Keferstein, Herschel, etc.
          Plications the result of subsidence of fold; thickened strata resulting from erosion of granitic nucleus of mountain, ... Whitney.
        With the intervention of geosynclinals (Hall).
          Subsidence caused by weight of sediments (Hall), and deep-seated condensation (Hunt); mountains only relief features of eroded conti-

nents, in earlier times somehow elevated (Buffon, de Montlosier, Lesley); subsidence resulting in motion or fermentation and pressure, which, with moderate accession of heat from below, cause metamorphism, etc., (Hall) [Continental elevation not explained].

Subsidence the principal cause of the corrugations of the earth's strata, - - - - HALL.

Subsidence not the principal cause of the earth's corrugations, but only of their position and direction. A zone of plastic material in aqueo-igneous fusion beneath the crust, augmented by subsidence causing vulcanic phenomena and softening of deep crust, forming lines of weakness along which are developed results of contraction of the earth and of the deep crust itself, - - - - - - - - - - HUNT.

Subsidence caused progressively by lithification below, and increasing density, and afterward aqueo-igneous fusion, metamorphism and slaty cleavage, and determination of line of weakness and yielding to horizontal pressure; no elevation except by crushing together, with upswelling and corresponding down swelling Heat partly primitive, partly of chemical origin. Continents and ocean basins resulting from unequal radial contraction. [No explanation of elevation without plications.] - - - - - - - - - - LE CONTE.

Subsidence an incident of general contraction. Copious sedimentation along geosynclinals. Finally, plications, shoving along fractures, and some crushing, resulting in elevation. Geanticlinal elevations discriminated. Increased pressure from the side of the great oceans, - - - - - - - - - - - - - DANA.

Fluidity not necessarily primitive (Wurtz, Mallet).

Fluidity caused by contractional evolution of heat.

Heat resulting from pressure and chemical action. VOSE.

Heat resulting from crushing of earth's crust,

with accompanying thermal and mechanical consequences, and variations in rate of increase of hypogeal temperature, - - - - MALLET.

Meridionality of crust-structures due to primitive tidal action. Fluidity contractional, tidal, and perhaps primitive. Sedimentation along geosynclinals located in position and direction by the lunar tidal actions on the primitive earth; mashing together with plications and metamorphism; consequent elevation and corresponding depression; the depression progressively removed by re-fusion, and the mountain standing-somewhat arch-like, with a molten or highly heated core and lower density; weight of mountain producing strains in the crust, mountain consequently undergoing secular subsidence. Geanticlinal elevations produced by lateral pressure resulting from contraction, and secondarily, in part, from weight of mountains. Submarine geosynclinals and geanticlinals as well as continental, and hence no greater contractional pressure from oceanic side, - - - THIS WORK.

Various other suggestions have been made during the history of geological speculation, most of which have never gained any particular repute. M. de Boucheporn conjectured that each geological revolution was the result of a sudden change in the direction of the earth's axis, caused by collision with a comet. The shock before the last, for instance, left the equator in the position of the Andes chain; the last left it in the actual position; the next will produce still another revolution. Geologists have also considered the possibility of a change in the axis resulting from a redistribution of the land and water — but this more especially to explain vicissitudes of climate.*

* Sir Wm. Thomson, *Brit. Assoc. Rep.*, 1876, Part II, p. 11; *Trans. Geol. Soc., Glasgow*, iv, 313; Haughton, *Proc. Roy. Soc.*, xxvi, 51, April 4, 1878; *Nature*, xviii, 266-8; G. H. Darwin, *Trans. Roy. Soc.*, clxvii, Part I; I. F. Twisden, *Quar. Jour. Geol. Soc.*, Feb., 1878; Airy, *Athenæum*, 22 Sep., 1869; Croll, *Geol. Mag.*, Sep., 1878; E. Hill, *Geol. Mag.*, June, 1878. See also Laplace: *Système du Monde*, ed. 1824, p. 392. For some recent views on the tendency of the earth's crust to subside under pressure, see J. Starkie Gardner, in *Nature*, xxviii, 323-7, August 2, 1883.

This speculation, however, generally leaves the cause of the change, even if real, unaccounted for. Rev. O. Fisher suggested, on the strength of Darwin's theory of the separation of the moon from the plastic earth, that perhaps the ocean basin represents the cavity left on that occasion.*

§ 11. UNEQUAL THICKNESS OF THE PLANETARY CRUST.

Let us recur for a moment to the physical conditions coëxisting with the mountain masses whose origin we have sought to discover. With the progressive development of wrinkles, groups of wrinkles and continental expanses, a gradual differentiation of different regions of the planetary surface would be in progress. This would produce that diversification of conditions which would be attended by an ever-increasing diversification in the organic aspects of land and water — since, as will be remembered, this discussion concerns for the present a planet upon which water has existence. As we can hardly suppose conditions on such a planet, under which no molecular disintegration would take place, we must conclude that the emerged and uplifted folds and synclinorian arches of the crust would be exposed to perpetual denudation; and this would ultimately thin the crust along the axes of the great folds and arches to such an extent that the mountains of anticlinal structure would tend to become mere shells filled with molten matter, or at least matter of a very high temperature. This condition of mountain masses would of course impart to them a density less than that of the average crust beneath the plains. As another result, the mountain crests would be lines of great relative weakness; and hence any pressure acting from beneath would be most likely to find relief through mountain summits. At the same time, the heated matter within and beneath the

* O. Fisher, *Nature*, xxv, 243–4.

mountain would be exposed to a freer radiation than the matter beneath the plain, and for this reason the solid crust should be able to thicken with a pace somewhat equal to the wastage by denudation. But if tidal movements of the crust, or currents or tidal swells in the subjacent liquid should create a predisposition in the molten matter to seek and frequent the spaces under the mountain anticlinals, this cause might interfere with the thickening due to the unusual exposure of a mountain convexity to the process of radiation, and thus preserve the unusual thinness which tends to result from surface erosions.

Now, tidal influences would tend to cause currents in the molten interior. As soon as the crust shall come to possess any sensible rigidity, the height to which the tidal swell would rise would be somewhat less than that which the same attraction would produce in a fluid. The underlying fluid would, therefore, press against the under side of the tidal arch. If at such a time, a vent should exist or be opened in the arch, the fluid would escape, and this would determine currents toward the place of outlet. Such vents would be most likely to be opened when the crest of the tidal swell should coincide with the line of weakness along a mountain anticlinal. The result would be an influx of molten matter from all directions; and the effect of this would be to prevent thickening of the mountain fold, if it did not actually reduce its thickness. Further than this, the very existence of permanent swells or folds in the crust would be the condition of translatory movements in the underlying liquid. The partial rigidity of the crust, as just stated, would cause the underlying liquid to press against it. This pressure would be transferred westward from point to point. There would be a time when the apex of the tidal swell would be near the base of an anticlinal fold. It is, therefore, obvious that the pressure in this situation would initiate an actual motion of the fluid

in the direction of relief — that is, toward the crest of the anticlinal. It is quite true that the tidal pressure would reach and pass the anticlinal before the relief which the latter would afford could be fully realized. But the fluid would have received an impulse toward the anticlinal which would live for some time after the tide had passed. This impulse would be renewed at every semi-rotation of the planet perpetually. I imagine that the consequence would be the perpetual transference of more highly heated matter to the region under the fold, and the prevention of normal increase of thickness.

On the contrary, some causes may exist for a greater than average thickness under masses of ocean waters. In the *first* place, the continual accumulation of sediments would not be fully offset by fusion upon the under side of the crust; nor even to such extent as the secular cooling of the planet and thickening of the crust would imply. The accumulation takes the initiative, and the removal from below is the reaction. The time which separates the action and the reaction would give opportunity for some uncompensated accumulation. But, in the *second* place, the normal circulation of oceanic waters would keep a stratum of nearly ice-cold water upon the bottom, spread over the ocean's floor. This is a colder temperature than the mean temperature of the atmosphere in any except subarctic and arctic regions. The planetary crust, therefore, is exposed to a more effective cooling temperature under the oceans than on the land. *Finally*, the water in contact with the crust under the oceans is a better conductor of heat than the atmosphere in contact with the land. These three reasons would conspire to produce a thicker crust under the oceans than under the continental surfaces.

CHAPTER III.

SPECIAL PLANETOLOGY,

OR PRESENT CONDITION AND COSMOGONIC HISTORY OF THE PLANETARY BODIES OF OUR SYSTEM.

§ 1. THE EARTH.

Each orb has had its history. For ours,
It blazed and steamed, cooled and contracted, till,
Tired of mere vaporing within the grasp
Of ruthless condensation, it assumed
Its present form, proportions, magnitude—
Our tidy ball, axled eight thousand miles.—DAVID MASSON.

ACCORDING to nebular theory, all the members of our system must pass sooner or later, through the same succession of stages. The circumstances of different planetary bodies, however, have differed widely, and the details of their evolution have assumed very diversified aspects. The principal factors concerned in the special histories of these bodies, so far as we can judge, are mass, volume, distance from the sun, age, and magnitude of the tidal actions exerted upon them. Connected with mass and volume are the quantity of atmosphere and its density on the planetary surface, and hence the temperature of steam formation and the thermal effect of solar radiation. Let us consider attentively the probable influences of the diversified conditions of planetary existence in our system, beginning with those bodies most accessible to physical inquiry.

Our planetary home occupies the temperate zone of the solar system. It presents us also an array of facts from which we may verify many of the conclusions deductively

reached from physical principles. We have here innumerable surface indications of a former high temperature upon the exterior of the globe. Numerous other phenomena testify to the perpetuation or perpetual production of a high temperature at all considerable depths beneath the surface. The records of extinct life testify to a progressive subsidence of temperature during long past ages, and possibly also, to a diminution of solar heat; and wide-spread sheets of marine sediments declare the former existence of a universal ocean.

1. *Condition of the Earth's Interior.*— That great heat exists within the earth is abundantly demonstrated; but the condition of the general interior has been much discussed. Sir Humphrey Davy,* Daubeney † and others maintained that chemical action was adequate to produce the thermal, dislocating and orographic phenomena which have been observed. Mr. F. M. Endlich has recently detailed remarkable thermal and explosive manifestations on the island of Dominica, which he thinks clearly attributable to chemical action, but which so much resemble volcanic action as to give good countenance to Davy's theory.‡

An opinion for a long time more widely accepted, was that which conceived the great interior mass of the earth as existing in a molten state, and the solid portion as constituting a mere film commonly designated the crust. This conception has come down from Descartes § and Leibnitz,‖ and until recently, has been very widely accepted.

* Davy, *Phil. Trans.*, 1828, 1832.

† Daubeney, *Jameson's Edinb. New Phil. Jour.*, liii, and *Encyc. Met.*, pt. 40. See also Ennis: *Origin of the Stars*, and Studer: *Geologie der Schweiz.*

‡ Endlich, *The American Naturalist*, xiv, 761–72, November, 1880.

§ Descartes: *Principes de la Philosophie*, 1644, pt. iv, §§ 2, 44, 72.

‖ Leibnitz: *Acta Eruditorum*, January, 1693, and *Protogæa*, 1749. Compare also Newton: *Principia Mathematica Philosophiæ Naturalis*, 1667, and Buffon: *Epoques de la Nature*, 1778. For statement of Leibnitz' speculations, see Part IV, § 4.

The whole doctrine of a molten interior was objected to by Professor W. Hopkins* on the ground that the phenomena of precession and nutation could not be what they are unless the earth were solid, or had, at least, a crust from 800 to 1,000 miles in thickness — sufficiently thick to give it a high degree of rigidity. The idea was taken up from new considerations and reinforced by Sir William Thomson in several remarkable scientific memoirs,† in which he distinctly maintained the theory of a solid globe; though he claimed that the solidity of the central portion may be the result of pressure of the superincumbent portions. Geologists and physicists generally have shown a disposition to acquiesce in the judgment of such mathematicians. It does not appear, however, to the writer that the astronomical considerations are conclusive, since whatever external attractions are exerted on the protuberant crust about the equator would be almost equally felt by the protuberant magma underneath the crust, and the solid and liquid portions of the equatorial protuberance would tend to move consentaneously. It is quite true that the crust-protuberance would be slightly more affected than the molten protuberance beneath it, both because it would be slightly nearer the attracting body, and because the eccentricity of successively interior zones may be regarded as successively less. Still, if the thickness of the crust is held to be but a few miles, these differences must be almost too slight to enter into calculation, and would be mostly concealed by the presumable viscosity of the molten magma, and the friction upon itself and the enveloping crust. The defects in the argu-

* *Trans. Roy. Soc.*, 1836, p. 382; 1838, p. 38; 1840, p. 193; 1842, p. 48. His three memoirs for 1839, 1840 and 1842 embrace a complete investigation of the subject. See, also, *On the Geological Theories of Elevation and Earthquakes* in *Brit. Assoc. Rep.*, 1847, pp. 33-93; also *Quar. Jour. Geol. Soc.*, viii, 56.

†Sir W. Thomson, *Trans. Roy. Soc.*, May, 1862; Thomson and Tait: *Nat. Philosophy*, vol. i.

ment for internal solidity, based on the phenomena of precession and nutation, were pointed out by Delaunay,* who maintained that the motions of precession and nutation are so slow that the internal fluid, in consequence of friction and viscosity, would partake precisely of the motion of the crust. Archdeacon Pratt, however, dissents from Delaunay,† while General Barnard holds that Hopkins' results are vitiated by an oversight.‡ The problem has also been discussed by Hennessey and Haughton.§ Sir William Thomson informs us also that Professor Newcomb does not admit the validity of the reasoning from precession and nutation,‖ and that Newcomb's doubts led him to a reinvestigation of the problem, the result of which was a confirmation of the doctrine of internal solidity, with some qualifications in the actual case. In a still later utterance, however, Sir William Thomson admits that "the arguments derived from the phenomena of precession and nutation present considerable difficulties, and, indeed, do not afford us, at the present time, a decisive answer.¶ In reference to this particular argument for internal solidity we may, therefore, unite with Rev. O. Fisher in pronouncing it obsolete.**

This, however, is not to abandon the theory of internal solidity. There still remains a body of considerations lying in the border ground between terrestrial and cosmical physics, which furnish evidence not yet invalidated,

* *Comptes Rendus*, 1868; translated in *Geological Magazine*, v, 507, Nov., 1868. Also *Cours Élémentaire d'Astronomie*, 643, 644.

† Pratt: *Figure of the Earth*, 4th ed., 133–6.

‡ Barnard, *Problems of Rotary Motion*, Smithsonian Contrib., No. 240, *New Addendum*, p. 42, vol. xix, 1871.

§ Hennessey. *Phil. Trans.*, 1851, 545; *Trans. Roy. Irish Acad.*, 1852; *Phil. Mag.*, Sept., 1860.

‖ Sir W. Thomson, *Glasgow Address*, Brit. Assoc., 1876, *Amer. Jour. Sci.*, III, xii, 342.

¶ Sir W. Thomson, *Trans. Geol. Soc., Glasgow*, 1879, p. 48.

** Rev. O. Fisher: *Physics of the Earth's Crust*, London, 1881, p. 22. This is a very important work.

that the earth must possess a high degree of rigidity. These considerations are supplied by the phenomena and the philosophy of tides; and have been likewise profoundly discussed by Sir William Thomson * and Archdeacon Pratt.† Were the terrestrial crust so yielding as to offer only fluid resistance to tidal action, it would rise and sink with the waters of the sea, so that the ocean tides would produce no increase or diminution of depth.‡ If, on the contrary, the earth were perfectly rigid, the whole tidal action would be developed in the waters, and the tides would increase the depth to a certain extent. The amount of this increase of depth has been calculated, but tidal observations have not yet been sufficiently exact to determine how the facts correspond with the theory of a perfectly rigid globe. The actual tide, however, seems to be somewhat less than the theoretical tide, and this affords some inductive ground for the theory that while the earth possesses a high degree of rigidity it is not perfectly rigid. Perfect rigidity would not, indeed, exist even in a globe of steel. Sir William Thomson has shown that if the earth were as rigid as steel the amount of its yielding to tidal action would be such that the ocean tides would be only two-thirds of what they would be with perfect terrestrial rigidity;§ if the earth were no more rigid than glass, the relative rise of the ocean tide would give a depth only two-fifths‖ of that on a perfectly rigid globe. Now the theoretical height of the tides has been calculated on the assumption of perfect terrestrial rigidity; and it is incredible that the actual tides should be only two-thirds of the requirement of theory without a discovery

* Sir W. Thomson, *Phil. Trans.*, 1863, p. 574; *Trans. Geol. Soc., Glasgow*, vi, 48-9.

† Pratt: *Figure of the Earth*, 4th ed., 138-40.

‡ See explanations, Pt. II, chap. ii, § 6, 1.

§ Archdeacon Pratt brings out the result "three-fifths."

‖ According to Pratt, "two-ninths."

of the discrepancy by means of observation. The whole earth must, therefore, be more rigid than glass. Such a degree of rigidity could not be imparted by a rocky crust having a thickness of fifty or a hundred or five hundred miles. Such rigidity may well be conceived to result from the general solidification of the interior. This, however, as before explained, would not result from the law which correlates solidifying point with amount of pressure sustained.

Mr. G. H. Darwin, in the course of his researches on the cosmic influence of tides, has incidentally arrived at confirmations of the doctrine of internal rigidity. He has shown that the diurnal and semi-diurnal bodily or deformative tides produced in the earth by the moon are not sufficient to reveal their existence in the secular acceleration of the moon's mean motion, though Sir William Thomson had assumed the two phenomena reciprocally connected.* The support of mountain masses implies also a high degree of rigidity. Mr. Darwin has shown that either the materials of the earth have about the strength of granite, at 1,000 miles from the surface, or they have a much greater strength nearer the surface.†

Still more recently Mr. (now Professor) G. H. Darwin has subjected the rigidity of the earth to a new discussion.‡ Abandoning the study of diurnal and semi-diurnal tides as too much influenced by meteorological accidents, he fixes on the lunar fortnightly declinational tide, and the lunar monthly elliptic tide. Using for data the Tidal Reports of the British Association, and the Indian Tide Tables, for a period of thirty-three years, at fourteen different ports in England, France and India, and taking due account of the interferences of the land masses of the

* G. H. Darwin, *Proc. Brit. Assoc.*, Dublin, 1878, *Nature*. xviii, 581.

† G. H. Darwin, *Proc. Roy. Soc.*, June 16, 1881.

‡ Paper read at the British Association, Southampton meeting, 1882. Published in *Nature*, xxvii, 22-3, Nov. 2, 1882.

earth, he finds, after a most laborious calculation, that, taking all the observations together, there "seems to be some evidence of a tidal yielding of the earth's mass," but that "the effective rigidity of the whole earth is about equal to that of steel." If only the Indian observations are used for a period of forty-eight years, the rigidity appears to be somewhat greater. "On the whole, we may fairly conclude," he says, "that, while there is some evidence of a tidal yielding of the earth's mass, that yielding is certainly small, and the effective rigidity is at least as great as steel."*

Admitting the general solidity of the earth, it is still evident that large supplies of molten matter exist within. Now we may rationally conceive three independent causes of a state of liquefaction at some depth beneath the surface.

(1.) There may be a zone too deep for solidification by cooling and too shallow for solidification by pressure. Or, in more exact terms, the downward increase of terrestrial temperature for a certain distance may be more rapid than the rise of that function of pressure which produces solidification; but at greater distances from the surface, less rapid than the rise of the same function. During the first interval the pressure will not be sufficient to produce solidification at the temperature existing; but during the deeper descent the pressure will be enough or more than enough to produce solidification at all temperatures attained.

It appears probable that the earth's internal tempera-

* The use of all the data gives

$$x = .676 \pm .076,\ y = .029 \pm .065,$$

where the approximation to complete rigidity is expressed by the approximation of the value of x to unity; and the value of y approaches zero as the amount of fluid friction diminishes. The numbers given with alternative signs are the probable errors. The use of only the Indian data gives

$$x = .931 \pm .056,\ y = .155 \pm .068.$$

ture does not continue to increase downward in uniform ratio with the depth, but that the rate of increase diminishes. As to the internal pressure, it must increase at a rate *greater* than the increase of depth; since it is demonstrated that the density of terrestrial matter increases toward the centre. The mean density of rocks at the surface is about 2.65, while the mean density of the whole earth is about 5.5. The density of the centre is made 10.74 by Pratt, who takes surface density at 2.75; and 9.59, by Waltershausen, who takes surface density at 2.66. The law of increase of density is unknown, but Waltershausen has assumed a formula* which gives the density inversely as the square of the distance from the centre; and Archdeacon Pratt has adopted and independently established the formula of Laplace, which makes the increase of the density vary as the square root of the increase of pressure. Each successive layer of uniform thickness must add, therefore, an increasingly greater amount to the pressure exerted upon the parts within, and also to their density, unless we assume that the compressibility of terrestrial matter exists only within certain limits of pressure.

(2.) In the next place we may suppose that at all depths beneath the surface the pressure is such that the fusing point is higher than the actual temperature, so that a state of solidity exists. If, now, the pressure within any region becomes diminished to a certain extent, the fusing point may be lowered to the actual temperature, where a state of fusion will supervene. Now, we may conceive the pressure to be diminished by the opening of a fissure from the surface. In this case, all the matter relieved may dissolve into a state of fusion, and this first

* Waltershausen: *Rocks of Sicily and Iceland*, p. 315. His formula is

$$\rho' = P - (P - \rho) r^2$$

where ρ' is the density at the distance r from the centre, ρ is the surface density and P the density at the centre.

fused matter may be crowded upward through the fissure by the pressure of contiguous matter, which, in turn, as soon as relieved, will be fused and ejected through the fissure in a similar way. Thus, it may be conceived, a copious fissure outflow of melted matter might be occasioned. Or, we may conceive the relief from pressure to result, as Professor William Hopkins suggested, by the partial support of an overlying arch bulged up by lateral pressure. Or, finally, we may look to the removal of vast overlying formations by surface erosion, as the source of such diminution of deep pressure as would lower the fusing temperature to the actual temperature. Mr. Clarence King has considered this cause attentively, and has enunciated the opinion that it answers the requirements of the case.* He has remarked that periods of copious volcanic overflow have followed periods of extensive erosion of mountains and plateaus, and that the succession in the nature of the erupted materials at different localities and different epochs is such as is best explained by the supposition of isolated lakes of molten matter, such as would arise from local and somewhat sudden diminution of pressure.†

(3.) We may conceive that heat and fusion result from some mechanical crushing pressure. With Mallet and others we may conclude that local fusion is produced through the crushing effects of enormous lateral pressure resulting from the secular contraction of the earth in its slow process of cooling. Mr. Mallet advocated this view

* King: *Geolog. Exploration 40th Parallel*, i, p. 706, seq.

† In the foregoing paragraph I have employed the usual language, but, as before explained (p. 270), I do not consider it exact, since the solidification which exists at great depths and at a high temperature, is not analogous with normal crystalline freezing, but is merely a consolidation by confinement of molecules in fixed positions. Pressure *lowers* the normal freezing point of molten rocks instead of raising it. But the principle stated is valid under either view.

with great ability and great persistence.* But it has been opposed as inadequate by numerous competent writers.† By some it has been shown that the total contraction of the earth is insufficient, and by others, that the effects are so much diffused as not to attain a condition of disturbance at distinct localities. It may fairly be claimed, nevertheless, that the effects of contraction would be diffused only in proportion as all the physical conditions of the earth's crust are everywhere uniform; while such uniformity is contradicted by all our familiar observations on the crust. So far as secular contraction gives rise, therefore, to lateral pressure, we must expect the crushing, and therefore the heating effects, to be accumulated in the weakest regions of the crust.

But a cause of crushing pressure which seems to me more adequate than secular cooling is suggested by Sir William Thomson's and Archdeacon Pratt's and, we may add, Professor G. H. Darwin's, demonstrations of tidal effects in a globe as rigid as steel or glass. May not the tidal deformations of the earth's crust be the source of the internal heat which manifests itself in fluidity? The whole value of the lunar tidal oscillation in a yielding globe should be about 58 inches. In a globe as rigid as glass it should therefore be about 34.8 inches, and in one as rigid as steel, 19.33 inches. The whole tidal oscillation under the joint maximum influence of the sun and moon in a perfectly yielding globe would be about 81.2 inches.

* Besides a long series of memoirs on the theory and phenomena of volcanoes and earthquakes, cited in the author's *Syllabus*, p. 73, the reader may consult, especially, Mallet, *On the Temperature Attainable by Rock-crushing, and its Consequences*, Phil. Mag., July 1875, I–13. and *Amer. Jour. Sci.*, III, x, 256–68, and xii, 463; also *Phil. Mag.*, v, i, 19–22.

† Sir W. Thomson, *Nature*, Jan. 18 and Feb. 1, 1872; O. Fisher, *Quar. Jour. Geol. Soc., Lond.*, xxxi, 469–72, May 12, 1875; *Phil. Mag.*, iv, l, 302–19, Oct., 1875; *id.*, v, i. 38–42; *Physics of the Earth's Crust*, ch. iv, v, vi. Criticisms are made also by Gen. G. J. Barnard, *Smithsonian Contributions*, No. 240, and by E. W. Hilgard, *Amer. Jour. Sci.*, III, vii, 535–46, June, 1874, and *Phil. Mag.*, July, 1874, 41.

The amount in a globe of glass would therefore be, when at a maximum, 48.72 inches and in a globe of steel, 27.06 inches. Should the terrestrial globe yield to the extent of any one of these amounts, the crushing effect experienced by the superior zones of the crust would not be uniformly distributed, since variations in structure and hardness and surface configuration would preserve certain portions from any change, and the whole amount of the interstitial displacements would be accumulated in the remaining portions. It does not seem at all improbable that the transformation of such enormous mechanical force into heat should suffice to bring to a state of fusion volumes considerable enough to answer all the requirements of the thermal manifestations of modern times, as well as the terrestrial movements of modern earthquakes.

The extended series of observations on earthquake phenomena collected by the late M. Alexis Perrey and by the British Association, are generally thought to indicate a real connection between such phenomena and the positions of the sun and moon. Thus (*a*) earthquake shocks are more frequent at the time of lunar syzygies than at the quadratures.* As the tidal effects of the moon and sun are as 5 to 2, their conspiring effects at the syzygies are as 7 and their conflicting effects at quadratures are as 3. If the seismic consequences of a range from 7 to 3 are observable as a differential — that is, if a tidal influence represented by 4 is a reality, then still more must a tidal influence represented by 5 or 7 be a reality.

(*b*) Seismic phenomena are more frequent when the moon is in perigee than when in apogee.† The difference between the maximum and minimum distances of the moon from the earth is about 31,355 miles. The tide-pro-

* A. Perrey, cited in *Amer. Jour. Sci.*, II, xxxvii, 1; III, xi, 233; *Pop. Sci. Monthly*, xvii, 457.

† *Pop. Sci. Monthly*, xvii, 458.

ducing efficiency of an attracting body is inversely as the cube of the distance. The lunar tide in perigee will therefore be to the lunar tide in apogee as 1.487 to unity. Here is a variation amounting to 49 per cent of the apogee tidal efficiency. A variation of 49 per cent of the minimum tide-producing efficiency is, it thus appears, the cause of a certain observed variation in earthquake action. The whole lunar force, therefore, may be the cause of the regular body of seismic phenomena.

(*c*) Earthquakes are more frequent with the moon in the meridian than with the moon in the horizon. In the former case, the lunar tide is at flood or nearly so, and in the latter, nearly at ebb. This result confirms the conclusion that lunar attractions cause relative movements in different parts of the terrestrial crust, and show that the elevatory effects are more disturbing than the ebb-tide subsidences. When the crust over two opposite quarters of the earth's surface subsides simultaneously with corresponding elevations over the two intervening quarters, it perhaps results that the subsiding quadrants are more uniformly and more firmly braced than the rising quadrants, and would therefore experience less local motion than they.

The observational determination and measurement of the geological tide-wave is a subject of extreme delicacy. Were all the disturbing influences acting on the oceanic waves suspended for a period, observation would readily determine the actual fluctuation caused by lunar and solar attractions, and the difference between these and the fluctuations deducible on the theory of a perfectly rigid globe would reveal the extent which the earth falls short of perfect rigidity. It is probable that tidal observations, made under the direction of the highest science, will ultimately eliminate disturbing effects arising from winds, barometric pressure and other causes, and make known the actual ex-

tent of tidal fluctuations in the open sea. Sir William Thomson has pointed out some conceivable experiments which would result in the very desirable solution of this problem. He supposes a water pipe twelve kilometers in length, submerged to protect it from variations in atmospheric pressure, and turned up at each end into the free atmosphere. Then, if the earth were perfectly rigid, and the pressure of the air equal at the two extremities, the water would rise in the more southern end during the passage of the moon over the meridian. Or, if a plumb line were suspended from a great height, and could be kept perfectly free from atmospheric disturbance, it would be deflected always toward the nearest tidal swell, except that when the moon were in the horizon or in the meridian, the attractions from opposite directions would neutralize each other. The greatest deflection would always be at the distance of 45° north or south of the position corresponding to the moon's declination, and the greatest deflection for any particular locality would be when the moon is 45° above or below the horizon. The greatest deflection of the line, however, would be only one twelve-millionth of its length, and this movement could hardly be made perceptible in a line of any practicable length.

2. *Submeridional Trends in the Earth's Primitive Structure.*— As important tidal influences must always have existed on the earth's surface, we may continue to discover in the oldest records of the earth's solidifying state, some traces of tidal action. I am inclined to think we discover such in the prevailing meridional trends of the oldest mountain ranges. I have stated that the transmeridional progress of the tidal swell in early incrustive times on any planet, must give the forming crust structural characteristics and aptitudes trending from north to south. I have stated also that the horizontal component of the tidal action on a lagging tidal swell would tend to give

the swell an actual motion of translation toward the west. Suppose the tide-wave to lag an hour behind the moon's meridian passage, it can readily be shown that the horizontal component of the moon's attraction upon the wave is one two hundred and twenty-sixth of the whole tide-producing effort of the moon.* Such a motive to actual translatory motion is by no means inconsiderable — the less so when we reflect that it is not directly opposed by gravity, as in the case of the tidal elevation, but only by the friction and inertia of the water.

When, therefore, the earliest wrinkles came into existence their axes would be meridional or submeridional. Now, some of the oldest beginnings of mountain development upon the earth are seen in the submeridional Laurentian ridges; in some of the Appalachian ranges, as the Blue Ridge, the Highlands of New York and Black Mountain of North Carolina; in some ranges of the Rocky Mountains, as Colorado, Medicine Bow and Park Ranges, in the Humboldt Range, and in the whole system of the so-called "Basin Ranges." Not materially later are the Green Mountains, the White Mountain system, the other principal orographic foundations of the Rocky Mountain, Sierra Nevada and Cascade chains, all equally meridional. In Europe, the Scandinavian range, the Urals, the Cambrian Mountains, the East Adriatic Alps; in Asia, the Yablonoi, the ranges of Indo China, the Malayan peninsula and islands, and those of Japan, Kamtchatka and northeastern China; in Africa, the entire east and west coast ranges, and those of Madagascar, all conform approximately to the direction of the meridian. It is also proba-

*If in the formula previously given (p. 233) we assume in the case of the moon and earth, $\alpha = 15°$, T O = 3959 and E T = 240,000, then $T A = F \times \frac{3959}{240000} \times \tan 15° = .00442\ F = \frac{1}{226}\ F$ nearly, where F represents the moon's attraction at the earth's surface and T A represents roughly its horizontal component at the distance of 15° from the zenith point.

ble that the foundations were early laid for the Sierra Madre Mountains in Mexico, and the Andes and the Serro Espinaco and Organ Mountains of South America. The crests of these mountain ranges may probably be regarded as ancient co-tidal lines, and these mountains are, to some extent, frozen billows, in the solidifying terrestrial surface, thrust, indeed, far above their original altitudes by the lateral pressure to which the shrinkage of the earth's interior has subjected them.

More than this, the whole general expression of the earth's surface configuration should preserve traces of the same primitive tidal action. (1) The original continental masses should trend generally with the meridian. This is the fact with North America, South America, Greenland and Africa. Moreover, an ancient Scandinavian continent stretched from Spitzbergen to the Straits of Dover, while most of other parts of Europe were sea bottom. The ancient, but now much wasted continent which embraced Australia, New Guinea, Borneo and the Philippine Islands, had a submeridional trend. The Mascarene continent, including Madagascar, stretched north and south. The group of New Zealand islands, with the contiguous submarine mass, is elongated meridionally. (2) The great ocean basins and their submarine topography should reveal a similar influence. Accordingly the Atlantic and Pacific have their longer axes north and south, and the submarine topography of the Atlantic, so far as known, generally corresponds. As to the configuration of the Pacific Ocean, Prof. J. D. Dana pronounces it "remarkable," and calls attention to the fact that "nearly all the ranges of islands over the Pacific Ocean, and even the longer diameters of the particular islands, lie nearly parallel with the great mountain ranges of the Pacific coast of North America." This arrangement he refers to the structure of the infra-Archæan crust. The method of sub-

sidence of the coral islands over a breadth of more than a quarter of the earth's circumference develops similar and parallel trends.* (3) Many accessory features of land and water might be expected to retain traces of early geognostic conformations now partially obliterated. I think we may discover these in the basin of Hudson's Bay and the seas and sounds stretching thence northward to the Arctic Ocean; in Baffin's Land and Baffin's Bay; in the valleys of the St. Lawrence, Mackenzie and Mississippi Rivers, and the Nile, Volga, Ural, Obi, Yenesei, Lena, Indus, Ganges, Brahmaputra and others; in the general trend of the West Indian Islands; in the form of Great Britain and the contiguous islands, in the Baltic, the Red and Caspian Seas; in Novaya Zemlia and the Gulf of Obi; in Kamtchatka, the Sea of Okhotsk, the Japan Sea, the Yellow Sea; in the great alternating bays and peninsulas of the south of Asia; and finally, in the north and south trends of minor features which have been determined immediately by the strike of geological formations, such as the Adriatic, the Ægean and the Italian peninsula, Lakes Tanganyika and Albert Nyanza in Africa, and in Lakes Michigan and Huron and in Saginaw, Georgian, Thunder, Green and Grand Traverse Bays pertaining to these lakes in North America.

But there are many terrestrial features which do not conform to the requirements of this theory. In reference to these there are two observations to be made: (1) When we regard the general expression conveyed by the aggregate of the earth's surface features, we find that the general meridional impress is unmistakable. (2) The meridional features are generally connected with the most primitive geognostic condition, and the transmeridional features can generally be shown to be of later origin, and to owe their existence to agencies which came into being only in the

*Dana, *Amer. Jour. Sci.*, III, v, 442-3.

later progress of the world's development. The most important of these are: *First*, the transverse stretch of the continent of Eurasia. Now, when we look at a map of this continent we see that it is distinctly impressed by profound meridional characteristics. The numerous great rivers flowing northward along their several valleys almost interlock with the great bays projecting northward from the Indian Ocean. The general land area is clearly marked by a series of meridional rugosities, and the fact that the intervening depressions are now permanently above the sea level is an unimportant circumstance. Were this continent to undergo a subsidence, the waters of the Arctic and Indian Oceans would meet at several points. In confirmation of these views we learn that the oldest known rocks of China — the old Archæan gneisses — maintain a pretty uniform strike from north-northwest to south-southeast.* Further, it cannot be doubted that the lateral pressure of oceans has contributed greatly to the development of folds along lines parallel with the ocean shores. This is an important part of the immediate agency which has uplifted so many coastwise mountain ranges. The ocean shore is indeed generally a feature which has been already determined by the movement of the primitive tidal swell; but if an ocean shore from any cause stretches across the meridians, contrary to the influence of the tidal swell, there must exist a strong motive for the development of transverse mountain ridges. Now such a relation exists between the mountains of central Asia and the Indian Ocean; and between the Pyrenees, Alps, Carpathians and Caucasus, and the Mediterranean Sea — once much longer, broader and deeper than at present. *Secondly*, the mountains of central Europe and the Mediterranean Sea. The sea undoubtedly sustains some causal relation to these mountains, as well as the Atlas chain in north Africa.

* Von Richthofen: *China*, vol. ii.

But in its insular and littoral features we can even trace some relation to a deep-seated meridional structure. This is exemplified in the chain of Corsica and Sardinia; in the Italian peninsula and the Adriatic; in the Ægean; in the Syrtes Major and Minor, and in the truncated eastern extremity. How the Mediterranean and Indian Ocean shores came to have general transmeridional trends is a question which must find its solution in the events of Mesozoic and Cænozoic geological history. It suffices to observe that the action which determined these shore lines belongs to medial and later geologic times, when the geotidal influences had ceased to be active, and exerted themselves only in the form of a store of meridional predispositions which the powerful strains borne by a greatly thickened crust might well be supposed adequate to overcome. *Thirdly*, the valley of the Amazons is a great transmeridional feature. It occupies, however, like the Amur, a great post-palæozoic basin. This stretched southward from the mouth of the Amazons — like the ancient intra-Mediterranean prolongation of the Gulf of Mexico stretching northward — and really constituted a primitive meridional feature, such as will probably be revealed in the geological structure of Asia. This southward basin seems to have been closed up in southern Brazil by the development of converging ranges of mountains on the east and west limbs of South America; so that the present valley of the Amazons is merely the transverse dimension of an ancient depression at its widest part.

3. *The Earth's Age, with Methods of Calculation.*— As to the numerical expression of the age of the world, various guesses and calculated results have been given on a previous page (p. 179). The grounds of various estimates of the age of the world or of certain periods may be enumerated as follows:

(1.) The time required for the sun to contract from a

nebulous condition, or from the orbit of the earth to its present limits. Professor Newcomb says the heat evolved by contraction from an infinite distance would last only 18,000,000 years.* A temperature permitting the existence of water on the earth would have been reached 10,000,000 years ago.

(2.) The time which the sun will require to cool from its present condition to a darkened or planetary state. Newcomb says the sun at its present rate of radiation will be as dense as the earth in 12,000,000 years; and it is quite likely to be long before that time that we are to expect the permanent formation of a continuous crust.†

(3.) The time required for the earth to cool from incipient incrustation to its present state, based on the thermal conductivity of rock-masses and the rate of increase of heat toward the earth's centre. Sir William Thomson concludes that this time cannot exceed 80,000,000 years.‡ Rev. O. Fisher, on a similar basis, calculates that the incrusted age of the world cannot exceed 33,000,000 years. M. Elie De Beaumont calculated that 38,359 years must have passed after the beginning of incrustation, before the rate of cooling in the general interior would surpass that of the crust. At this epoch the formation of mountains would begin.§

(4.) Relative times required for the deposition of all the rocky sediments. This method by itself furnishes no clew to absolute times, but only to time ratios. It makes the thickness of a bed of sediments the measure of the time consumed in its deposition. Undoubtedly, each bed is thus measured; but it cannot be assumed that a constant relation exists between time and thickness of sedi-

* Newcomb: *Popular Astronomy*, 509.

† Newcomb: *Popular Astronomy*, 513.

‡ Thomson and Tait: *Nat. Phil.*, 1st ed. Comp. Croll: *Climate and Time*, 335. Fisher: *Physics of the Earth's Crust*, 71.

§ De Beaumont: *Les Systèmes de Montagnes*.

ments. At some epochs, and probably during whole periods and ages, the energy of the forces of deposition must have been more rapid than at other epochs and during other intervals of time. During the same interval the rate of deposition must be more rapid in one region than in another. This difference must arise from differences in the activity of the same class of forces, and from differences in the kind of agency employed. Fragmental sediments accumulate more rapidly than calcareous; and the ratio of the two which is generally adopted regards one foot of limestones equivalent to five feet of sandstones or shales.

Notwithstanding unavoidable inaccuracies, the method furnishes results of considerable value and interest. If the maximum thicknesses of the formations are taken from the same geognostic region, as for instance the region of Appalachian upbuilding, the *ratio* of the thicknesses may be nearly the same as in another region where the rate of accumulation is less. By taking the limestones from the same region we avoid exaggerating estimates for the same periods. The geognostic region of most active accumulation during Eozoic time was the Laurentian; that during Palæozoic time was the Appalachian, and that during Mesozoic and Cænozoic time was the Rocky Mountain region and that of the Great Plains. Within each region we may assume the progress of sedimentation uniform. We do not know that the progress in one region during one time is comparable with the progress in another region during another time; but, so far as concerns shore action, we are compelled to assume it to be so. For instance, we must assume that ten thousand feet of Tertiary sediments accumulated by shore action in the Rocky Mountains correspond to the same length of time as ten thousand feet of the same kind of sediments, accumulated in the Appalachian region during Palæozoic time. We

can understand, however, that the *total* sedimentation in a given length of time must have been greater in the later periods, when the land areas were more extensive, and river drainage brought larger contributions to the sea-bottom deposits. What allowance should be made for river action in the later ages it is impossible to state with any precision; but it will not probably exceed the requirements to allow one-half from the fragmental deposits in the Tertiary lakes and seas of the Rocky Mountain region, and one-fifth from the fragmental deposits of the Mesozoic ages of the same region.

This general method of determining time ratios has been employed by Professor James D. Dana,* who gives the following table for maximum thicknesses along the Appalachians:

		Fragmental Rocks.	Limestones.
1.	Potsdam Period	7,000	200
2.	Rest of Lower Silurian	18,000	6,000
3.	Lower Silurian Era	25,000	6,200
4.	Upper Silurian Era	6,760	600
5.	Devonian Age	14,300	100
6.	Carboniferous Age	16,000	125
	Totals, feet	87,060	13,225

Supposing limestones accumulate at one-fifth the rate of fragmental sediments, the above numbers become respectively (1) 8,000; (2) 48,000; (3) 56,000; (4) 9,760; (5) 14,800; (6) 16,625. These numbers have nearly the ratio of 1 : 6 : 7 : $1\frac{1}{4}$: 2 : 2. "Hence, for the Silurian, Devonian and Carboniferous ages, the relative duration will be $8\frac{1}{4}$: 2 : 2, or not far from 4 : 1 : 1. Or, the Silurian Age was *four* times as long as either the Devonian or Carboniferous; and the Lower Silurian Era nearly *six* times as long as the Upper Silurian."

For the Mesozoic, Professor Dana announces the time ratios as, Triassic 1 : Jurassic $1\frac{1}{4}$: Cretaceous 1. For the

* Dana: *Manual of Geology*, 3d ed., 381, 481, 585.

Cænozoic he finds the maximum thickness of the Tertiary deposits 16,000 feet, with very little limestone. But as river action increased with enlargement of the land areas, he reduces this thickness one-half to arrive at the approximate amount of marine sedimentation. Then, assuming the Quaternary to have been one-third as long as the Tertiary, he gets the ratios, Palæozoic 12 : Mesozoic 3 : Cænozoic 1.

The following table of the approximate thickness of the several geological formations in Europe—making no discriminations for limestones or for fluvial contributions—has been compiled by Rev. S. Haughton, of the University of Dublin:*

			Feet.
1.	Eozoic		26,000
2.	Lower Palæozoic.	Lower Silurian	25,000
		Upper Silurian	5,500
3.	Upper Palæozoic.	Devonian	9,150
		Carboniferous	14,600
		Permian	3,000
4.	Neozoic	Triassic	2,200
		Jurassic	4,590
		Cretaceous	11,283
		Nummulitic [Middle Eocene]	3,000
		Tertiary	6,000
			110,323

From this, by disregarding Quaternary and including the Nummulitic in the Cænozoic, we get the ratios, Eozoic 4.7 : Lower Silurian 4.5 : Upper Silurian 1 : Upper Palæozoic 4.9 : Mesozoic 3.3 : Cænozoic 1.6.

In attempting to compile results from the latest determinations of thickness in the several formations, nothing better can be done than to accept for the Eozoic Great System, the conclusions of Sir William Logan for the Laurentian region. These give us for the maximum thickness of the Laurentian 30,000 feet, of which limestone masses aggregate 3,500 feet, or, deducting intercalated beds of gneiss, 2,800 feet. For the Huronian,

† Haughton, *Phil. Mag.*, xxvi. 545, Dec. 20, 1877.

Logan's estimate was a maximum of 20,000 feet, with only thin layers of somewhat impure limestone, which we may set down at 100 feet.

Turning to the Palæozoic ages and the Appalachian region, in its extension to Nova Scotia, we may deduce the following statement of maximum thicknesses:

PRIMORDIAL GROUP.—*Acadian* attains 10,000 feet in the Ocoee slates and conglomerates of east Tennessee. *Potsdam*, 5,600 feet of limestones, sandstones and shales in Newfoundland, of which 200 feet may be set down as limestones. Total fragmental, 15,408; limestone, 200.

CANADIAN GROUP.—*Calciferous* attains 7,000 feet in east Tennessee, of which 3,000 feet are fragmental and 4,000 feet chiefly limestones. *Quebec*, 6,600 feet in Newfoundland, including 3,200 feet of limestone. *Chazy*, 600 feet in east Tennessee, principally limestone. Total fragmental, 6,400 feet; limestone, 7,800.

TRENTON GROUP.—*Trenton*, in east Tennessee, 2,000 feet of limestones and shales, of which 500 feet may be assumed as shales. *Utica*, 700 feet of shales in Pennsylvania. *Hudson River*, 1,259 feet of limestone at Anticosti, or 2,000 feet of shales near Quebec, or 6,000 feet of shales in Pennsylvania.* Total fragmental, 7,200 feet; limestones, 1,500 feet.

NIAGARA GROUP.—*Medina* attains 2,500 feet of conglomerates and sandstones in Pennsylvania. *Clinton*, 2,555 feet of shales in Pennsylvania. *Niagara*, in Pennsylvania embraces 450 feet of marl or fragile shale, and 1,200 feet of the same with thin limestone layers. Consists of 350 feet of limestone in Iowa, which is nearly equivalent. Total fragmental, 6,605 feet; limestones, 100 feet.

SALINA GROUP presents a maximum of 1,650 feet in Pennsylvania, of which not over 100 feet can be set down as limestones.

*Lesley: *2d Penn. Survey*, G 6, p. 152.

LOWER HELDERBERG GROUP presents a maximum at Cape Gaspé of about 1,500 feet of limestones.

ORISKANY GROUP attains 520 feet of calcareous shales and argillaceous sandstones in Pennsylvania, of which not over 50 feet could be counted as limestone.

CORNIFEROUS GROUP.—*Cauda Galli Grit* attains 300 feet in eastern Pennsylvania, and *Corniferous* limestone 500 feet in northwestern New Jersey.

HAMILTON GROUP.—The Gaspé sandstones present a maximum of 6,000 feet. Otherwise we might take the *Marcellus* shale, with some argillaceous limestone, in Pennsylvania, at 1,300 feet (I. C. White)—not over 50 feet limestones—the *Hamilton* proper in Pennsylvania, at 1,375 feet (I. C. White) of shales and sandstones, and the *Genesee*, also in Pennsylvania, at 700 feet of black calcareous shale (not over 50 feet limestone), making fragmental 3,275 feet, and limestone 100 feet. But we shall adopt the Gaspé measure.

CHEMUNG GROUP.—*Portage* amounts to 1,700 feet of flaggy sandstones and blue shales in Pennsylvania. *Chemung*, 3,200 feet of sandstones, shales and conglomerates along the Appalachians. Total, 4,900 feet fragmental.

CATSKILL GROUP aggregates 6,000 feet of sandstones, shales and conglomerates along the Appalachians, reaching 7,544 feet in Carbon county, Pennsylvania, all of which is fragmental except 14 feet of calcareous breccia.

LOWER CARBONIFEROUS series in Pennsylvania aggregates 5,560 feet of shales and sandstones with some (say 500 feet of) limestones. On the eastern border, 6,000 feet of sandstones, marls, marlites and gypsum; in Tennessee and Alabama, 2,170 feet of limestones, which is equivalent to 10,850 feet fragmental. It may be best to adopt the Pennsylvania measure, which gives fragmental, 5,010; limestone 500.

UPPER CARBONIFEROUS series.—Maximum thickness of *Coal Measures* in Nova Scotia, 14,570 feet (in Pennsylvania, 9,000 feet and over).

Turning next to the Mesozoic and Tertiary ages, the following statement of maximum thicknesses is afforded by the most recent investigations.

TRIASSIC.—*Koipato* Group, of the West Humboldt Range, 6,000 feet, strictly non-calcareous. *Star Peak* Group, 5,300 feet of quartzites, and 4,600 feet of limestone (King). Total fragmental, 11,300 feet; limestones, 4,500 feet.

JURASSIC.—In the West Humboldt Range, 1,800 feet of impure limestones and 4,000 feet of shales. Say fragmental, 4,800 feet; limestones, 1,000 feet.

CRETACEOUS.—In the Uinta region: *Dakota*, 500 feet of sandstones and clays; *Colorado*, 2,000 feet of clays, marls and some (say 100 feet of) limestone; *Fox Hills*, 4,000 feet of sandstones (King). Total fragmental, 6,400 feet; limestones, 100 feet.

TERTIARY.—*Laramie*, in Green River Basin, 5,000 feet, mostly sandstones. *Wahsatch*, in Rocky Mountains, 5,000 feet of marls and sandstones. *Green River*, in southwestern Colorado (Cope), 2,670 feet of shales. *Bridger*, 5,000 feet of argillaceous and arenaceous strata. *Uinta*, 600 feet of grits and conglomerates, in Uinta Range. *White River Group*, 2,000 feet of calcareous clays, alternating with sandstones, in Wind River Mountains. *Truckee Group*, 4,000 feet, chiefly of indurated, trachytic mud. *Loup River Group*, 2,000 feet of sandstones, on the Great Plains. *North Park Group*, 300 feet of sandy and marly deposits. Total fragmental, 26,470 feet; limestones, 100 feet.

From these results may be compiled the following table of maximum thicknesses:

	Fragmental.	Limestones.
EOZOIC	47,100	2,900
LAURENTIAN	27,200	2,800
HURONIAN	19,900	100
PALÆOZOIC	75,999	12,250
SILURIAN	37,155	11,200
LOWER SILURIAN	29,000	9,500
Primordial	15,400	200
Canadian	6,400	7,800
Trenton	7,200	1,500
UPPER SILURIAN	8,155	1,700
Niagara	6,605	100
Salina	1,550	100
Lower Helderberg		1,500
DEVONIAN	19,214	550
Oriskany	470	50
Corniferous	300	500
Hamilton	6,000	
Chemung	4,900	
Catskill	7,544	
CARBONIFEROUS	19,630	500
Lower Carboniferous	5,060	500
Upper Carboniferous	14,570	
MESOZOIC	22,500	5,600
TRIASSIC	11,300	4,500
JURASSIC	4,000	1,000
CRETACEOUS	6,400	100
TERTIARY	22,470	100
Total stratified rocks to Quaternary	168,069	20,850
Fragmental and calcareous		188,919 feet.

To arrive at a truer expression of time ratios, we must probably diminish Mesozoic fragmental deposits one-fifth, and Tertiary deposits perhaps one-half, and increase all calcareous strata five-fold. The combined results give the numbers entered, on a following page, in the table of the "Estimated Length of Geological Periods." These, for the sake of easier comparison, are reduced to percentages in another column.

From this table it appears that the Lower Silurian was 4.6 times as long as the Upper Silurian; the Devonian was nearly one-fourth the duration of the Silurian; and the Carboniferous was as long as the Devonian. The Palæozoic was $3\frac{1}{4}$ times the length of the Mesozoic and $9\frac{1}{2}$ times the Cænozoic. The Tertiary was one-ninth of the time since the lower Silurian, while Sir Charles Lyell

makes it one-fourth the time since the Cambrian.* Ramsay makes the Devonian and Triassic united equal to the Jurassic, Cretaceous and Cænozoic;† but the tabular ratios here determined make the former $2\frac{1}{2}$ times the latter. The Tertiary, it appears, was one-sixteenth the Mesozoic and Palæozoic united; while Professor Dana makes it one-fifteenth.‡

With a view to arriving at some absolute measure of geological periods, we may assume Post-Tertiary time to be one-fourth as long as Tertiary.§ We may also assume the Glacial epoch to be two-thirds of the Post-Tertiary; and may further assume the Azoic period of the earth's sedimentary history to be equal to the Eozoic; and the pyrolithic or presedimentary incrustive history to be equal to the Azoic and Eozoic united, and here designated Archæan. We are thus furnished with an expression for the incrusted age of the world in terms of sediments, and may, for convenience, calculate a percentage value for each interval as shown in one of the columns of the table referred to. These are the final time ratios. If we assume the whole incrusted age of the world as 80,000,000 years, according to Sir William Thomson, the time to be allotted to each period is such as shown in another column of the table. If, again, according to Professor Newcomb, we allow 10,000,000 years for the time since sedimentation began, which, calculating from the tabular time ratios, makes 13,844,662 years for the time since incrustation began, we get the series of values given in the last column of the table.

*Lyell: *Principles of Geology*, 10th ed.

†Ramsay, *Proc. Roy. Soc.*, No. 152, 1874.

‡He, however, counts the *Laramie* with MESOZOIC, while here it is regarded as Tertiary. My former convictions, in accord with the views of Marsh and Cope, have been here abandoned in deference to the recent positive statements of C. A. White. (*Amer. Jour. Sci.*, III, xxv, 207-9.)

§Prof. Dana puts the Post-Tertiary equal to one-third of the Tertiary; but he does not include the *Laramie* group in the Tertiary, nor does he accord the Tertiary accumulations the enormous thickness which they have recently been shown to possess.

ESTIMATED LENGTH OF GEOLOGICAL PERIODS.

Formations.	Rock measure, feet.	Per-centage.	Thomson's Basis, years.	Newcomb's Basis, years.
PYROLITHIC	*123,200*	*27.77*	*22,216,000*	*3,845,000*
ARCHÆAN	*123,200*	*27.77*	*22,216,000*	*3,845,000*
Azoic	61,600	13.88	11,104,000	1,922,000
Eozoic	61,600	13.88	11,104,000	1,922,000
Laurentian	41,200	9.26	7,408,000	1,282,000
Huronian	20,400	4.62	3,696,000	639,000
Palæozoic	*137,244*	*30.93*	*24,744,000*	*4,282,000*
Silurian	93,150	21.00	16,800,000	2,907,000
Lower Silurian	76,500	17.25	13,800,000	2,388,000
Primordial	16,400	3.70	2,960,000	512,000
Canadian	45,400	10.23	8,184,000	1,416,000
Trenton	14,700	3.32	2,656,000	460,000
Upper Silurian	16,650	3.75	3,000,000	519,000
Niagara	7,100	1.60	1,280,000	221,000
Salina	2,050	.46	368,000	64,000
Lower Helderberg	7,500	1.69	1,352,000	234,000
Devonian	21,964	4.96	3,968,000	686,700
Oriskany	720	.17	136,000	23,500
Corniferous	2,800	.63	504,000	87,000
Hamilton	6,000	1.35	1,080,000	186,900
Chemung	4,900	1.11	888,000	153,700
Catskill	7,544	1.70	1,360,000	235,400
Carboniferous	22,130	4.98	3,984,000	689,500
Lower Carboniferous.	7,560	1.70	1,360,000	235,400
Upper Carboniferous.	14,570	3.28	2,624,000	454,100
Mesozoic	*45,360*	*10.22*	*8,176,000*	*1,415,000*
Triassic	31,540	7.11	5,688,000	984,400
Jurassic	8,200	1.85	1,480,000	256,100
Cretaceous	5,620	1.26	1,008,000	174,400
Cænozoic	*14.669*	*3.31*	*2,648,000*	*458,300*
Tertiary	11,735	2.65	2,120,000	366,900
Post-Tertiary	2,934	.66	528,000	91,370
Glacial	1,956	.44	352,000	60,920
Post-Glacial	978	.22	176,000	30,460
Total Crust	*443,673*	*100.00*	*80,000,000*	*13,845,000*

It can hardly be doubted that the total thickness of the Laurentian and Huronian series of strata is much greater than has been observed or estimated. Few, I think, would hesitate to admit that Eozoic Time was as long as Lower Silurian, but our table only makes it about four-fifths as

long. It is not at all improbable that some large portion of the primitive strata designated Azoic, as well as the entire Pyrolithic crust, has been removed through ascent of the isogeothermal planes, so that the remaining thickness, even if measurable, would not afford a correct relative measure of Pyrolithic and Archæan time. The effect of an augmentation of Pyrolithic and Archæan time would be a diminution of the relative length of all the later periods. It may be mentioned, on the contrary, that strong probability exists, as before shown, that the accumulation of sediments was more rapid in primitive times than during the later periods. The shorter year, the more rapid rotation of the earth, the superior tidal efficiency of the moon and sun, not to mention more energetic chemical action, all disclose the existence of geological forces which must have acted, in remote times, with a degree of energy for which the agencies of modern times present no adequate measure. These facts point toward a diminution of the ratios for remote ages, and an increase of those for later times. This would raise the numerical value of post-glacial time above the figures indicated by more direct, and apparently more trustworthy estimates remaining to be noticed. The alternative is therefore to diminish the whole time allowed since incrustation and sedimentation began.

(5.) Calculation based on the obliteration of the rotational effects of the upheaval of a continental mass. Rev. S. Haughton has attempted to calculate a minor limit for the time since the elevation of Europe and Asia, at the end of the Nummulitic epoch.* He shows that the uplift of this continental mass must have displaced the axis of maximum inertia of the earth through sixty-nine miles, in the direction of the meridian of the Andes. The axis of rotation would thus acquire a motion on the surface of a

* Haughton: *Philosophical Magazine*, December 20, 1877, 534-46.

right cone around the axis of figure, with its pole at the distance of sixty-nine miles from the pole of the axis of figure; and this motion would be perpetual unless destroyed by friction. But the place of the ocean would always be slightly behind the place of the rigid earth, and some friction would constantly result, which would tend to destroy the wabbling movement of the earth. As astronomy is now unable to detect any such movement, though the precision of its instruments should detect a wabble of five feet (instead of sixty-nine miles), the problem is presented, What time has been occupied in the destruction of the wabble? From researches on tidal friction,* which causes a retardation amounting to one second in the length of the day in 100,000 years, Professor Haughton now calculates that if Europe and Asia were *suddenly* elevated, a wabble of sixty-nine miles would require 640,730 years for its extinction. If they were formed by sixty-nine geological uplifts, each of which displaced the axis of figure through one mile, then, supposing the radius of the wabble to be reduced from one mile to five feet in the interval between each two successive convulsions, the minimum time required for the extinction of the wabble would be 27,491,000 years. If, again, the rate of upheaval of Europe and Asia was so slow that the increase of the radius of an assumed wabble of five feet was exactly destroyed by friction during each wabble, then the total time required for the production of Europe and Asia would be 4,170,000 years.†

*Delaunay: *Sur le Ralentissement de la Rotation de la Terre*. Paris, 1866.

†It is erroneous to assume Europe and Asia produced entirely after the close of the Nummulitic epoch. This mid-Eocene disturbance elevated the Pyrenees, the Julian Alps, the Appenines and Carpathians, and probably extensive regions in Northern Africa, and through Central Asia as far as Japan and the Philippine Islands. But large masses of the European continent rose at intervals during Palæozoic and Mesozoic time. So that the period of the extinction of the wabble may have extended back far beyond the close of the Nummulitic epoch — a necessity provided for in the second and third suppositions of Professor Haughton.

Professor Haughton now attempts to employ the unit thus obtained in the calculation of the length of the earth's sedimentary history. To do this, he compiles the table of rock thickness before quoted, and then on the principle,

$$\text{Total sedimentary age} = \frac{\text{Total thickness of sediments}}{\text{Thickness of Tertiary rocks}} \times \text{Time represented by Tertiary rocks,}$$

he assumes the minor limit given above under the first supposition, and gets

$$\frac{110,323}{6,000} \times 640,730 = 11,700,000 \text{ years.}$$

This approximates Professor Newcomb's calculation of the sedimentary age of the world.

Since, however, it can hardly be assumed that Europe and Asia were uplifted *per saltum*, the above result for the sedimentary age of the world must be too small. If the formation of the continent occupied a million years, the total duration of sedimentary time would be nearly 37,000,000 years. Manifestly, however, the succession of uplifts extended back into Pre-Nummulitic time, so that the unit obtained cannot be regarded as representing Post-Nummulitic time.

(6.) The time since the middle of the last glacial period, based on the theory that epochs of glaciation on the northern hemisphere have been caused by extreme eccentricity of the earth's orbit. This theory has been carefully expounded by Professor Croll.* The last occurring epoch of maximum eccentricity, according to Stockwell's calculations† (supplemented by Croll's) were, before 1800 A.D., 100,000 years, 210,000 years, 310,000 years, 750,000 years and 850,000 years. Those at 210,000 and 850,000 years are the most striking. Professor Croll regards the last glacial period as extending from 240,000

*Croll: *Climate and Time*.

†Stockwell, *Smithsonian Contributions to Knowledge*, xviii; R. W. McFarland, *Amer. Jour. Sci.*, III, xl, 456.

to 80,000 years ago. The maximum of 850,000 years, he thinks, fell in the Miocene period; and a maximum at 2,500,000 years ago he regards as belonging to the Eocene. If, according to Croll, the advent of the last glacial period occurred 240,000 years ago, this number represents Post-Tertiary time, which, according to the foregoing table, represents 0.4 of one per cent of the whole time since incrustation began, and would make that time 60,000,000 years. Again, if 2,500,000, according to Croll, represents the time since the *beginning* of the Tertiary Age, the whole incrusted age of the world would be 131,600,000 years, which I do not feel disposed to allow. If 100,000 years be taken as marking the *middle* of the last glacial epoch, then by the same table of ratios, the incrusted age of the world would be 33,000,000 years. Even this is 18,000,000 years more than Professor Newcomb's calculation allows when combined with the above tabular ratio for the Pyrolithic Aeon.

(7.) Estimates based on rates of erosions and deposition. The Niagara gorge has exercised the wits of a long series of observers. Mr. Robert Bakewell assumed the rate of recession to be three feet a year, from which he calculated the age of the gorge, seven miles in length, to be 12,300 years.* Messrs. Lyell and Hall, assuming a rate of one foot a year, obtained a result of 35,000 years.† Mr. E. Desor, on an assumed rate of .03 foot per annum, made the age of the gorge 1,232,000 years. Mr. Jules Marcou,‡ in 1863, found a recession of twelve feet in the Canadian fall at the base of the "Terrapin Tower," since

*R. Bakewell: *Introduction to Geology*, 260; Loudon's *Magazine of Natural History*, 1843-4.

†Sir Charles Lyell, *Proc. Geol. Soc., London*, 1842, 1843; *Travels in North America*, 1st Visit, ch. ii; *Principles of Geol.*, 8th ed.. 205; James Hall, *Boston Jour. Nat. Hist.*, 1843-4; *Geol. Fourth Dist. New York*, ch. xx, 1843.

‡Jules Marcou, *Bulletin de la Soc. géol. de France*, II, xxi, 290-300, 529, two plates. See also Ramsay, *Quar. Jour. Geol. Soc.*, xv, 212, 1859, who thinks the falls commenced during the deposition of the "Leda Clay," or a little before the close of the Drift period.

the trigonometrical survey, executed under the direction of Professor James Hall in 1842. This is a recession of .57 foot per annum at that point, and implies, if applied to the entire gorge, a period of 64,842 years. Mr. Thomas Belt,* after a careful examination, assumed the rate of recession at .01 foot per annum. But he announced the important discovery, if a fact, that the ancient gorge, from the whirlpool to St. David's, on the Canadian side, now filled with gravel, was excavated in pre-glacial times; and the old gorge apparently extended, also, up nearly to the present falls. In this view, the only post-glacial work is included between Queenston and the whirlpool, with the addition of an unknown, but probably small, portion of the gorge above the whirlpool. Mr. Belt assumes, however, in round numbers, that 20,000 years express the maximum limit of time since the commencement of the new gorge at Queenston. His own assumption of the rate of recession would give for the three miles below the whirlpool, 158,000 years, which, as Mr. Belt recognizes, is more than the time at our disposal for the incrusted history of the earth will allow. The accompanying diagram will illustrate Mr. Belt's views.

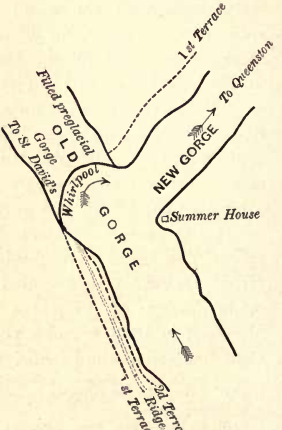

FIG. 53.—NIAGARA GORGE—OLD AND NEW.

Mr. James T. Gardner,

*Thomas Belt, *Quar. Jour. of Science*, April, 1875.

Director of the New York State Survey, has given attention to the rate of recession of Niagara Falls, reproducing Hennepin's narrative and illustration, and the map of the triangulation of 1842, by Mr. Blackwell.* On the latter he has laid down also the line of the falls as determined by the United States Lake Survey in 1875.† From this comparison is shown "the unexpected fact that the Horse Shoe Falls have receded, in places, 160 feet during thirty-three years, and that a large island has disappeared which formerly existed in the midst of the Canadian Rapids." In spite of some slight inaccuracy resulting from the independent datum points of the surveys of 1842 and 1875, the errors cannot be so great, as Director Gardner informs me, that the assumption of a recession of 100 feet in thirty-three years would involve any degree of uncertainty. This is an average of three feet a year, and implies 12,320 years for a gorge seven miles long. For the three miles below the whirlpool, this rate of recession requires 5,280 years, which, adding for some amount of work above the whirlpool, comes strikingly near to other estimates of post-glacial time, presently to be mentioned. At the same time, this is by far the most trustworthy determination ever made of the rate of recession of the Falls.

It may be added that I find it stated in the public prints that great changes took place at the Falls during 1880, and these were especially commented on at the annual meeting of "old settlers." The Canadian Fall is said to have changed more during the preceding year

* J. T. Gardner: *Report of New York State Survey for the Year 1879.*

† By a remarkable oversight the triangulation of the Lake Survey was not connected with the survey of 1842; although the permanent landmarks of the earlier survey were perfectly accessible, and such connection only was needed to shed important light on a highly interesting problem. The mutual adjustment of the two triangulations was made by Director Gardner in 1879; and while, as he writes (Feb. 21, 1883), the accuracy attainable is not as great as if the two triangulations had been referred to the same datum points, it is safe to assume that the true relative positions of the Horse Shoe Falls in 1842 and 1875 are shown without a probable error greater than twenty feet.

than during the twenty or thirty years previous. The Fall, "in the centre, has fallen back some 75 to 100 feet." Without claiming for these figures any considerable exactness, they may apparently be received as evidence of a more rapid recession than most students of the Falls have admitted, and they are strongly sustained by Mr. Gardner's more scientific determinations.

The gorge of the Mississippi River below the Falls of St. Anthony has been studied by Professor N. H. Winchell.* This, he argues, is entirely a post-glacial erosion as far as Fort Snelling. The mean rate from 1680 to 1856 appears to have been 5.15 feet a year, so that the time required for recession from Fort Snelling, eight miles, is 8,202 years. The date of the commencement of this part of the gorge, according to the geological indications, was "near the acme of glacial cold, or, at least, when the *effect* of that cold on the superficial accumulations was greatest."

Various estimates have been framed of the rate of deposition in deltas. Elaborate investigations have been made of the Mississippi delta under the auspices of the United States government. Messrs. Humphreys and Abbott,† by a careful comparison of the volume of the delta deposit with the volume of sediment transported annually to the Gulf of Mexico, estimate the age of the delta to be about 5,000 years. This, of course, supposes uniformity in the rate of deposition, and expresses the time since the adjustment of the present drainage system, and not since the "acme of glacial cold."

Similarly, the age of the Nilotic delta has been set down at 6,350 years.‡

*N. H. Winchell, *Quar. Jour. Geol. Soc., London*, Nov., 1878, 880-901; *Fifth Ann. Report Geol. Minn.*, 1876. See digest in Southall's *The Epoch of the Mammoth*, ch. xxiii.

†Humphreys and Abbott: *Hydraulics of the Mississippi*, 1861. But see also E. W. Hilgard, *On the Geology of Lower Louisiana, and the Rock Salt Deposit of Petite Anse*, Proc. Amer. Assoc., 1868, 327-40.

‡De Lanoye: *Ramses the Great.*

A recent writer calculates that the sediments of the three great rivers of China would fill the Yellow Sea and the Gulfs of Pe-chili and Lian Tung in 24,000 years; and in 36,000 years would extend the continent to its ancient limit at the 129th meridian, and south to the 29th parallel.*

The rate of continental erosion and consequent subsidence has been much studied within a few years. The following are some results. The surface is calculated to subside one foot in the basin of the Plata in 29,400 years;† in the basin of the Pei-ho in 25,218 years;‡ in the basin of the Thames, 9,600 years;§ in the basin of the Danube, 6,846 years;‖ in the basin of the Mississippi, 4,640 years;¶ in the basin of the Nile, 4,723 years; in the basin of the Yang-tse, 3,707 years;** in the basin of the Ganges, 1,751 years;†† in the basin of the Rhone, 1,528 years;‡‡ the Hoang Ho, 1,464 years;§§ the Po, 729 years;‖‖ in the basin of the three great rivers of China, the Yang-Tse, the Hoang-ho and Pei-ho, 1,687 years.¶¶ The general surface of England and Wales is estimated to subside by erosion one foot in 13,000 years, and the continental surface of Europe at large, one foot in five hundred million

*H. B. Guppy, *Nature*, xxii, 488. Mr. A. Woeikoff thinks the first period should be extended to 28,000 years. *Nature*, xxiii, 9.

†Higgins. But see T. M. Reade, *Nature*, xxii, 559; Guppy, *Nature*, xxiii, 35.

‡Guppy: *loc. cit.*

§Geikie; Huxley: *Physiography;* but see T. M. Reade, *Nature*, xxii, 559. J. Prestwich calculates that the matters in *solution* in the Thames are sufficient to lower the surface of the Thames basin one foot in 13,000 years. Address as President Geol. Soc., Feb., 1872, abstract, *Amer. Jour. Sci.*, III, iv, 413.

‖Geikie: *Man. Geol.*, ch. xxv.

¶Croll says 6,000 years (*Climate and Time*, 330), and so says Geikie. Mr. A. Tylor says one foot in 10,000 years (*Phil. Mag.*, 1850).

**H. B. Guppy, *Nature*, xxii, 486–8; but see A. Woeikoff, *Nature*, xxiii, 9.

††Geikie says 2,358 years (*op. cit.*), and so says Croll (*Climate and Time*, 331). See also, *Amer. Jour. Sci.*, III, xli, 458.

‡‡H. B. Guppy, *Nature*, xxii, 488.

§§Geikie.

‖‖Geikie.

¶¶Guppy. On river sediments see Reclus: *The Earth*, ch. lii-iv.

years.* Prof. Croll, on the basis of a much more extended examination, and a juster apprehension of the whole range of evidence, concludes that the general surface of the land is subsiding by erosion at the rate of one foot in five or six thousand years.

It is manifest that the action of water in lowering the surface of the land is two-fold, mechanical and chemical, and that investigators have not generally taken this fact into account, since they have studied chiefly the effects of erosive action as revealed in sediments. But chemical solution, of calcareous matters especially, amounts, in some regions, to almost as much as the processes of surface denudation, as Prestwich has shown for the basin of the Thames. Uniting chemical and mechanical agencies, the total diminution of the land must be much more rapid than is shown by the foregoing citation of results.

(8.) The rate of Bluff-recession and Terrace-formation. Professor E. Andrews has made a careful study of the formation of the terraces and sand beaches bordering Lakes Michigan and Huron, especially in the neighborhood of Chicago and the southern extremity of Lake Michigan.† He finds, from the present rate of erosion (5.28 feet per annum), that 2,720 years have been occupied in the recession of the bluffs which bound the lake at its present level. But above the bluffs are two successively higher sand beaches. By comparing their total contents with the contents of the modern beach (contemporaneous with the modern bluff, and therefore 2,720 years old), it appears that the two upper beaches have required 2,570 years for their accumulation. The sum of these numbers, 5,290 years, represents the whole time elapsed since the close of

*T. M. Reade: *Address*, *Liverpool Geol. Soc.*, 1876; *Nature*, 26 Oct., 1876; *Amer. Jour. Sci.*, III, xii, 462. Beyond question, this is a most extravagant estimate, and deserves citation merely as a curiosity.

†E. Andrews, *Trans. Chicago Acad. Sciences*, ii. See also digest of this memoir in Southall: *The Epoch of the Mammoth*, ch. xxii.

the glacial period. In other words, there is a bluff north of Chicago whose rate of recession has been ascertained by observation. The former position of the bluff has been learned by soundings in the lake, and therefore the whole volume removed, and the time required for the work. But the material removed has been redeposited in a terrace at the south end of the lake, whose volume has been measured, and whose age must be the same as that of the bluff. There are also two terraces in the rear of the bluff, and by comparing their volume with that of the modern terrace whose age has become known, we get the time which elapsed after the formation of the lake and before the beginning of bluff-erosion. The age of the upper terraces united with the age of the bluff gives the time since the beginning of the Champlain epoch. Dr. Andrews concludes finally, that the true time must be somewhere from 5,300 to 7,500 years. As this, according to the table of ratios previously given, is 0.22 per cent of the total time since the commencement of incrustation, the incrusted history of the world would be from 2,404,545 to 3,404,545 years.

It would not be surprising if Dr. Andrews had considerably underestimated the original volume of the sands in the two upper terraces. It is evidently their original, and not their present, volume which constitutes a measure of the time of deposition. But, since their abandonment by the lake, they have been exposed to all that wastage which, as we have seen, Professor Croll calculates to amount to one foot in 6,000 years. That is, supposing these upper sands to have been exposed 6,000 years, they have lost already one foot of their original depth. Due allowance for this wastage would lengthen the time required for the upper beaches by an important percentage, raising it, perhaps, nearly as high as the figures obtained for the St. Anthony gorge. Still, the method pursued is

unimpeachable, and the result must be regarded as fairly approximative.

(9.) Still another method of calculating the length of the last glacial period has been suggested by a passage in an address by Sir William Thomson.* "Any considerable area of the earth, of say not less than a kilometer in any horizontal diameter, which, for several thousand years, had been covered by snow or ice, and from which the ice had melted away and left an average surface temperature of 13° C., would, during nine hundred years, show a decreasing temperature for some depth down from the surface; and thirty-six hundred years after the clearing away of the ice, would still show a residual effect of the ancient cold in a *half rate of augmentation* of temperature downward in the upper strata, gradually increasing to the whole normal rate, which would be sensibly reached at a depth of 600 metres." Now, all the northern portion of temperate America has been buried beneath snow and ice for a thousand years and much more, during which a greatly diminished rate of augmentation was established; and, unless the time since the disappearance of the ice has been sufficiently prolonged for the normal rate to be restored, there must still exist a slower rate of downward increase of temperature under the surface of Michigan, for instance, than under the surface of Louisiana. If the rate of increase could be well established for regions once glaciated, and also for regions not glaciated, the difference in the rates would furnish a datum for calculating, on the principles employed by Sir William Thomson, the time since the uncovering of the glaciated areas. Even if no difference could be detected between Louisiana and Michigan, for instance, in consequence of the length of time since the disappearance of glaciers in Michigan, there

* Sir Wm. Thomson, Address Brit. Assoc., Glasgow, 1870; *Amer. Jour. Sci.*, III, xii, 340.

might be a difference in the rates in Louisiana and Winnepeg, or Norway House or Fort Churchill.

The best efforts of science thus far to arrive at a trustworthy numerical estimate of the age of the world have been signally foiled by the impossibility of obtaining the value of certain constant quantities in the problem. One may feel predisposed to trust preferably the more mathematical methods, or those based on radiation, conduction and condensation, as likely to furnish the closest approximation; since those based on rate of geological actions are liable to be vitiated by unsuspected and undiscoverable variations in the intensity of the action — all the more indeterminable because located in terrestrial periods separated by so many revolutions from the present observed order of events, which must furnish us our only rule of measurement. But even in the mathematical methods, it is indispensable to make enormous assumptions, with nothing better than a general judgment to be our guide. On the whole, I am inclined to accord at least equal confidence to the simple methods which address themselves to the later results of geological action, where the energy of the forces must have been quite comparable with the action of recent times, which falls under our direct observation. Such methods are those depending on observed and measured rates of erosion of river gorges and lakeside and seaside bluffs. Among these we have four attempts which may fairly be regarded as approximating exact solutions. These are: (1) The rate of recession of Niagara Falls, as lately announced by Director James T. Gardner, combined with the earlier suggestion of Mr. Belt in reference to the old gorge; (2) the rate of recession of the Falls of St. Anthony, as worked out by Professor N. H. Winchell; (3) the rate of recession of the lake bluff north of Chicago, and the determination of the volume of the upper terraces above the bluff;

(4) the age of the Mississippi River delta, as determined by Humphreys and Abbot. These four attempts are measurements of the time since the disappearance of the continental glacier, and the substantial agreement of the results adds to our confidence in them. The results are as follows:

1. By Niagara Gorge.....5,280 years.
2. By the St. Anthony Gorge.....8,202 years.
3. By Lake Michigan Bluffs.....5,300 to 7,500 years.
4. By the Mississippi River Delta.....5,000 years.

Now, when we recall that some time must be added to the result from the Niagara gorge for some small amount of work done above the whirlpool in post-glacial time; that the result from the lake bluffs must be increased in consequence of denudation of the upper terraces since they were first formed; and that something must be added, also, to the result from the Mississippi delta, in consequence of a commencement somewhat later than that of the other works, it will appear that these various results are singularly accordant, and point toward 6,000 or 7,000 years as the most probable interval since the commencement of the flood of post-glacial time. If we assume this at 6,500 years, the whole incrusted age of the world deduced from the table of ratios would be 3,000,000 years.

If our attempts to ascertain the age of the world, or the duration of any single period of its evolution, yield only uncertain results, they suffice at least to demonstrate that geological history has limits far within the wild conceptions of a certain class of geologists. They show, if we may credit the indications here regarded most trustworthy, a restriction of the modern epoch within limits not exceeding one-tenth or one-twentieth the duration sometimes assigned to it.* This conclusion, it may be

*The author has long entertained and often expressed this view. It has also been recently expressed by Prof. H. Carvill Lewis in a lecture at the *Franklin Institute*, Jan. 5, 1883. Also by Prof. G. F. Wright, in a paper before the *Boston Soc. Nat. Hist.*, March 7, 1883, noticed in *Science*, I, 269–71.

mentioned incidentally, bears on the antiquity of the Mediterranean race, since it is generally believed to have made its appearance during the later decline of the continental glaciers. It does not concern, however, the antiquity of the Black and Brown races, since there are numerous evidences of their existence in more southern regions, in times remotely pre-glacial.

§ 2. THE MOON.

Il manque quelque chose aux géologues pour faire la géologie de la Lune, c'est d'être astronomes. A la vérité il manque aussi quelque chose aux astronomes pour aborder avec fruit cette étude, c'est d'être géologues.—M. FAYE.

Die Anziehung welche die Erde an dem Monde ausübt, zur Zeit seiner ursprünlichen Bildung, als seine Masse noch flüssig war, die Achsendrehung, die dieser Nebenplanet damals vermuthlich mit grösserer Geschwindigkeit gehabt haben mag, auf die angeführte Art bis zu diesem abgemessenen Ueberreste gebracht haben müsse.—KANT.

1. *Planetological Retrospect.*—The moon's volume is .0203; its density .6167; its mass .0125,* the earth's corresponding constants being unity. The relative amount of heat originally possessed by the moon must therefore have been .0125; but its relative rate of radiation was .07442. The relative duration of corresponding planetary periods was therefore .1679. That is, the moon cooled nearly six times as rapidly as the earth, and its present stage is six times as far advanced, if we regard only the rate of refrigeration.† If the earth's incrustation began fourteen million years ago, and the moon's began at the same time, the moon reached the present terrestrial stage eleven and two-thirds millions of years since. The earth was only two-

*Or, according to Newcomb, .012279. The density given above is calculated on the assumption that the moon is a sphere having a diameter equal to that of its visible disc. But in fact the visible disc presents the least two of three diameters; and hence the actual density of the moon is slightly less than the value given above.

†From the formula in a note on p. 217, $T = \frac{H}{\Delta} = \frac{.0125}{.07442} = 1679$; and $.1679 = \frac{1}{5.933}$.

thirds through its Pyrolithic Æon. In truth, however, according to our present reasoning, the moon reached its incrustive stage in one-sixth the time required by the earth, reckoning from the epoch when the moon separated as a distinct mass of fire-mist; and the lunar stage, corresponding to the present terrestrial, must have been reached much earlier in the Pyrolithic Æon, and perhaps even before the earth's incrustation began.

The earth was then another sun to the supposable inhabitants of the moon, having an apparent diameter $3\frac{1}{2}$ times as great as the present sun — if we take no account of the earth's greater volume and the moon's less distance in remote epochs. Whatever the incrusted age of the world, the lunar stage corresponding to the earth's habitable condition was coeval with the self-luminous æons of our planet. By a simple calculation based on relative diameters and distances of the sun and earth from the moon, it appears that at equal temperatures the earth would supply the moon $12\frac{1}{2}$ times as much light and heat as the sun.* The temperature of the sun, however, was very much higher than that of the earth in the early incrustive stage; and the solar surface had probably not yet withdrawn to its present distance from the earth.

If the moon at that remote period had already attained

*Let E_1 = the thermal force of a unit of surface on the earth.
S_1 = the same on the sun.
d = mean distance of the sun from the moon
d' = mean distance of earth from moon.
R = radius of sun, and r = radius of earth.
e = number of units of radiating surface on the earth's hemisphere.
s = same on the sun.

Then $$E_1 = \frac{S_1 d^2}{d'^2} \text{ and } e = \frac{s r^2}{R^2}.$$

Hence the thermal force of the earth's hemisphere is

$$E = E_1 e = \frac{S_1 s \times d^2 r^2}{d'^2 R^2} = S_1 s \cdot \frac{d^2}{d'^2} \cdot \frac{r^2}{R^2}.$$

But $S_1 s$ is the sun's thermal force, and calling this unity, we obtain

$$E = \frac{d^2 r^2}{d'^2 R^2} = \frac{(92,330,000)^2 \times (3959)^2}{(240,000)^2 \times (430,000)^2} = 12.55.$$

to synchronistic axial and orbital motions (which, however, is improbable), it would result that one side was subjected to a constant radiation of heat from the earth, while at the oppositions, the same side received also the incessant heat of the sun. Simultaneously the apogeal side was turned from the influence of both bodies. Under such circumstances it is probable that all water resting on the heated hemisphere would be vaporized and a portion of the clouds, floating to the cold side, would be precipitated in fortnightly deluges of rain. During the next two weeks, the deluged side, through constant exposure to the solar heat, must have been scorched to such a degree that the atmosphere became burdened with clouds, and the satellite was completely wrapped in vapors, as I have to suggest may be the condition of Mercury at the present time. Even in our day, when the heat radiated from the earth must be nearly imperceptible, the constant exposure of one hemisphere of the moon to the sun's rays during two weeks, alternating with constant exclusion of solar heat during the next two weeks, may produce, as has been thought, a physical condition quite difficult to reason out. Lord Rosse calculated that the oscillation of temperature during a lunation must be as much as 500° Fahr. It is not impossible that the actual temperature fluctuates from two hundred degrees below zero to as much above; though Professor S. P. Langley's recent researches on the absorptive property of the terrestrial atmosphere, and the increased rate of radiation under diminished atmospheric pressure, reminds us that thermal vicissitudes on the moon's surface may not be as great as has been supposed.*

The fact that no cloudy vapors are ever revealed on our satellite's surface is sufficient proof that in its present stage it is destitute of surface waters. The absence of all indications of water and an atmosphere is a circumstance

* See this subject considered under the last head of this section.

which would not at first be expected on the basis of a theory which derives the moon from the mass of the earth. We must endeavor to explain it.

M. Sæmann suggested, a few years ago,* that in the progress of cooling, the water and the atmosphere may have entered into the pores of the lunar rocks; and on the basis of Durocher's experiments on the absorbent property of various minerals, he made a rough calculation which showed that the earth will eventually acquire sufficient porosity to absorb both the ocean and the air.† That the fluids of the moon have thus disappeared seems entirely reasonable on the ground of nebular theory; since, as I have shown, the moon's relative age is six times as advanced as the earth's, while the progressive cooling of any planet constituted like the earth must deepen the zone of rocks sufficiently cooled to permit water to occupy its pores, and afterward to afford space for the entrance of the planet's entire atmosphere.‡

* Sæmann, *On the Unity of Geological Phenomena in the Solar System*, Bull. de la Soc. géol. de France, February 4, 1861; translated in *Canadian Naturalist*, vi, 444-51.

† See this subject discussed hereafter in Part II, ch. iv.

‡ A general formula may be readily deduced which, by the substitution of the requisite constants will apply to any planet.

Let R = the radius of a planet:

r = the radius of the sphere within the zone whose pores are capable of absorbing the water of the planet:

i = the index of absorption by volume; that is, the volume of water absorbable by a unit of volume of rock.

W = the volume of water on the surface of the planet.

w = the relative amount of water surface on the planet.

d = mean depth of water beneath the water surface.

Then, disregarding the thin superficial zone which may be already saturated with water, we shall have

$$\frac{4}{3}\pi R^3 - \frac{4}{3}\pi r^3 = \frac{W}{i},$$

whence

$$r^3 = R^3 - \frac{3W}{4\pi i}.$$

But since $W = 4\pi R^2 w d$, we obtain by substitution,

$$r = \sqrt[3]{R^2\left(R - \frac{3 w d}{i}\right)}$$

2. *Tidal Forces on the Moon.*—The tidal protuberance upon the moon must have presented, in all stages of its evolution, a comparatively enormous development; and its influence upon the moon's physical condition and aspects must have been permanently recorded. As the moon's relative mass is .0125, this fraction represents the moon's relative tide-producing power upon the earth. The tides on the moon must, therefore, have always presented a development many times as great as the lunar tides on the earth. The problem of the linear height of the tide produced by the earth on the moon is quite difficult of solution, but a few considerations will show the way to an approximate result. (1) The height of the geal tide on the moon must be a direct function of the relative mass of the earth. (2) It will be in the inverse ratio of the radii of the earth and moon, since we may here assume that the same tidal force acting on larger and smaller

If r' = radius of the sphere within the zone capable of absorbing both water and air,
A = volume of the atmosphere reduced to its density at the surface of the planet, and
a = relative volume of the atmosphere, that of the planet being unity.

Then $$\frac{4}{3}\pi R^2 - \frac{4}{3}\pi r'^2 = \frac{W + A}{i},$$

And $$r'^2 = R^2 - \frac{3 R^2 w d}{i} - \frac{3 A}{4 \pi i}.$$

But $$A = \frac{4}{3}\pi R^2 \times a, \therefore \frac{3 A}{4 \pi i} = \frac{a R^2}{i},$$ and substituting,

$$r' = \sqrt[3]{R^2 \left(R - \frac{3 w d + a R}{i}\right)}$$

If D = the depth to which the planetary crust is already saturated with water, then

$$r = \sqrt[3]{\left(R - D\right) - \frac{3 R^2 w d}{i}},$$

And $$r' = \sqrt[3]{\left(R - D\right)^3 - \frac{3 R^2 w d + a R}{i}},$$

in which $D = \rho (t' - t) + c$, where ρ = rate of increase of temperature downward; that is, number of feet or other dimension to one degree of increase; c = depth from surface to constant temperature; t = constant temperature at depth c, and t' = temperature at which water passes into steam.

bodies, with other conditions the same, produces prolateness of the same eccentricity in the two bodies. (3) Other things being the same, the height of the geal tide on the moon will be directly as the force of gravity on the earth or inversely as that on the moon. In other words, the geal tide on the moon will be about eighty times higher than the lunar tide on the earth in consequence of the earth's superior mass; and six times as high, in consequence of the moon's inferior gravity at its surface; and it will be one-fourth as high in consequence of the moon's smaller size.* The product of these factors gives, roughly speaking, a geal tide on the moon about 120 times as high as the lunar tide on the earth.

I have already expressed the opinion that the deformation of the solid or incrusted earth through lunar tidal influence, probably reveals its existence in increase of volcanic and seismic phenomena at the epoch of lunar syzygies, and perhaps even in nearly the whole amount of internal heat existing in the earth. From this point of view, volcanic and seismic phenomena must always have been many times more violent on the moon than on the earth.

* That is, in general terms, $t = \mathrm{T} \cdot \frac{\mathrm{M}}{m} \cdot \frac{r}{\mathrm{R}} \cdot \frac{g}{g'}$ (see also general formula, p. 229), where M and m = the masses of two planets,

T and t = the heights of the tides borne by them respectively,

R and r = their radii,

g and g' = the force of gravity on their surfaces respectively.

Taking the values for the earth and moon from the *Encyclopædia Brit.*,

$$\frac{\mathrm{M}}{m} = 81.4, \ \frac{r}{\mathrm{R}} = .2725 \text{ and } \frac{g}{g'} = \frac{1}{.16547} = 6.043,$$

whence $t = 134$ T.

This result is sufficiently in accord with a remark of M. Faye (*Annuaire*, 1881, p. 721). "La marée terrestre, comptée à partir du niveau moyen des mers, est de $0^m.37$. La marée lunaire devait être de 40^m *et même plus.*" Now $\frac{40}{.37} = 108$. M. Faye adds in a note. "Si l'on pouvait tenir compte de la faiblesse de la densité moyenne de la Lune, et de ses dimensions primitives, plus grandes alors qu'aujourd'hui, on trouverait probablement plus de 40^m." The method of caiculation given in this note makes it $.37^m \times 134 = 49^m.58$. If we take the relation given in the text it is $.37^m \times 120 = 44^m.4$.

3. *Physical Aspects of the Moon.*— To render intelligible any reasoning respecting the physical history of later stages of the moon, it is desirable to offer a few explanations of the aspects of the lunar surface. To the unaided eye, the distribution of light and shade presents a configuration which, from the time of Plutarch, has been likened to the face of a man,* and which, by Helvetius, was regarded as a water surface, the various divisions of which have, by later selenographers, been designated seas, lakes and bays. The unaided eye also discerns some regions of peculiar brightness, and even some radial arrangements of bright and dark lines, as well as indications of a very complicated detail of structure in all parts of the surface. By means of optical instruments all these features are brought into wonderful distinctness. The study and mapping of the moon's surface have been pursued by modern selenographers with great assiduity, so that at the present time we have maps and descriptions of all parts of the lunar disc as detailed and exact as of any region of the terrestrial surface. Professor J. F. Julius Schmidt completed, in 1874, a map of the moon, on which he had labored for thirty-five years, and on which he had laid down, as the result of exact triangulations, the altitudes of 3,000 mountains, the position and form of 250 hills, 35,000 craters, and an immense number of minor features.† These studies, together with those of Lohrmann, Gruithuisen, Beer and Maedler, Nasmyth, Neison and others, have given us lunar positions which, in the central parts of the moon's disc, cannot be in error over 3,000 feet, while the altitudes of the mountains are exact within 100 feet.‡ Besides the results of triangulations, we possess

* Plutarch: *De Facie in Orbe Lunæ.*

† *Vierteljahresschrift der Astronomischen Gesellschaft*, Leipzig, ix. 232-6.

‡ "We have a better map of the moon's surface," says Professor Lewis Boss, of the Dudley Observatory, "than of the State of New York" (*Report New York State Survey for the year 1877*, p. 20); and this statement is true of the whole territory of the United States.

the beautiful photographs of the moon, executed by Rutherford, de la Rue and Draper; and these show certain features more distinctly than direct telescopic vision.

Selenographers arrange the features of the moon's disc under three general heads, Plains, Craters and Mountains; but the last two designations must be understood in a

FIG. 54.—THE MOON.

[Telescopically inverted. Hence the top is south, the bottom north, the right hand east and the left hand west.]

1. Tycho,
2. Copernicus,
3. Kepler,
4. Aristarchus,
5. Theophilus,
6. Ptolemæus,
7. Bullialdus,
8. Linné,
9. Hyginus,
10. Mare Serenitatis,
11. Mare Tranquillitatis,
12. " Fœcunditatis,
13. " Nectaris,
14. " Crisium,
15. " Frigoris,
16. " Imbrium,
17. " Nubium,
18. " Humorum,
19. Oceanus Procellarum.

special sense, and not as expressing any close analogy with terrestrial features. The plains occupy over half of the lunar disc. Most of them are dark and well defined,

while the remainder are light and undefined. The craters are divided into nine classes, and the mountains into twelve, but these numerous modifications need not be mentioned here.

In general character, all the principal craters, so-called, present a sub-circular form, surrounded by a rampart which slopes gently outwards, but descends precipitously on the inside to a depth considerably below the general level of the lunar surface. In the centre of the crater exist one or more mountain-like masses, which never rise, however, to the level of the surrounding rampart, and stand, generally in complete isolation from it. The vertical configuration of the crater will be better understood from the accompanying section through the crater Copernicus — more accurately styled a circle or walled plain.

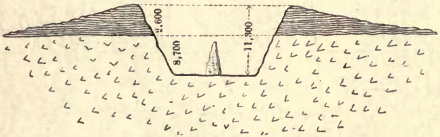

FIG. 55.—SECTION ACROSS THE CRATER COPERNICUS.

The features here shown are of grand dimensions. The diameter is 56 miles, the crest of the crater 2,600 feet above the general surface, and 11,300 feet above the bottom of the crater. The bottom is, therefore, about 8,700 feet below the general level. This depression of the interior is a uniform character of the craters or circles, and is especially marked in the smaller ones. The depressed bottom, moreover, as Sir John Herschel has remarked, is not a right plane, but presents a curvature conformable to that of the lunar surface, as if the matter had assumed form in a fluid state under the action of gravity. The central peak often rises to the height of

FIG 56.—MAP OF THE CRATER THEOPHILUS AND THE SURROUNDING REGION.*

*From Neison: *Der Mond.*

5,000 or 6,000 feet, but generally the central mass or masses is much less elevated. The surrounding rampart presents a succession of somewhat concentric, interrupted, terrace-like formations, as if produced by successive overflows of lava which have subsequently been disrupted and eroded in deep valleys. These characters are well illustrated in the accompanying map of the circle or crater Theophilus. This walled area is 64 miles in diameter, bounded by steep, lofty and variously terraced walls, which attain the remarkable elevations of 14,000, 16,000, 17,000 and 18,000 feet, as if the mountain masses of Mont Blanc, the Jungfrau, the Matterhorn and Monte Rosa had been piled around the valley of Switzerland. The general crest of the rampart is 3,200 feet, or probably higher, above the surface of the Mare Tranquillitatis. In the interior is a mountain cut by deep valleys into several separate masses, the highest of which is elevated 6,400 feet above the floor. From the bounding wall extends a lofty ridge about 80 miles across the Mare Nectaris. North of Theophilus stretches the Mare Tranquillitatis, which is diversified with numerous ridges and hill-ranges, radiating from Theophilus, and distinguished from the dark plain by their intenser light.

Tycho is another walled plain or vast sunken amphitheatre fifty-four miles in diameter. It is surrounded by a rampart sculptured in numerous terraces on the inner side, and which consists on the outer side of a mass of terraces and buttress walls, rising on the west 17,000 feet above the central floor, and on the east 16,000 feet, while the central mountain attains an elevation of 6,000 feet. The inner terraces are cut by deep gorges, and seem to bear some small craters. The outside of the rampart presents an irregular structure, and assumes the aspect of a confused mass of mountains. The region more remote is crowded with mountains, walled plains and crater-like

depressions and pits — the last-mentioned in countless numbers. Tycho, like Copernicus and Kepler, is the centre of a conspicuous system of light streaks radiating in all directions and spreading themselves over a fourth part of the moon's visible hemisphere. These cross indiscriminately all the other accidents of the surface — plains, craters, mountains and valleys. They are not seen best, like the other features of the disc, by oblique light, but are most distinct at full moon, and a few of the intensest can be distinguished when merely illuminated by light reflected from the earth. These bands are from ten to twenty miles wide, and stretch from 600 to 700 miles, while one of them crosses nearly the whole visible hemisphere of the moon — a distance of about 2,000 miles. The light of these streaks obscures many important structures in the surrounding region. Similar light streaks, less extensively developed, radiate from Copernicus, Kepler, Byrgius, Aristarchus and Olbers, and, to a still smaller extent, from numerous other centres, especially between the equator and 13° north latitude. It is a curious fact that the distinctness of all these streaks is increased by photography.

Besides these enormous walled areas, we find a multitude of smaller ones ranging down to a diameter of four or five miles; and also numerous still smaller formations of bright, circular outline, and steep, massive walls bounding depressions sometimes but half a mile in diameter. Finally, to this class belong also very numerous, small, isolated conical mountains or hills, from half a mile to two or three miles in diameter, having real crater-like pits in their summits. They occur on the crests of mountain masses, on the slopes of larger craters, on the ramparts encircling ringed areas, and in the bottoms of these sunken areas.

One further class of structures requires mention. These

are furrows or clefts in the surface — long, narrow, deep gorges or fissures, extending generally in right lines, sometimes branched or bent, and sometimes intersecting each other. They occur abundantly on the open plains without distinguishable beginning or end. They often pass through the middle of a mountain, or stretch from a crater into the surrounding plain. In other cases, they form a complicated net-work around some structure, or intersect the depressed floor of one of the larger crater forms. It is thought that not less than one thousand of these clefts have been laid down on the maps, and some of them attain a length of 200 to 300 miles. The two bounding walls are alike and generally rough, so that in some instances the cleft has the appearance of a chain of craters. The bottom of the cleft presents also a rugged aspect.

The description of these voiceless lunar solitudes, with their weird and grandiose features, cannot but awaken interest and excite the imagination. The scene is a wilderness of rocks and rents and pinnacled mountains and yawning pits. The sun rises on them slowly at the end of a fortnight of darkness, and his steady ray dispels the fierce cold of the departing wintry night. But no stir of conscious activity responds to day dawn, no bird of song rises on joyous wing to greet the rising sun. No murmur of a freshening breeze is heard among the tree tops, and no rippling rill prolongs its cheerful babbling down the rugged cleft in the mountain. The steady glare of sunlight warms the herbless and soilless surface, but no vapors rise to gather in a summer cloud. The wide area is lifeless, noiseless and motionless. This is the land of death. The mountains sleep in death, still lifting their dead and rigid forms to dizzy altitudes above the surface of a dead planet. The very pits sunken by thousands all over the convexity of the lunar world look like the collapsed sepulchres of a vast and neglected cemetery. The

rocky ramparts which rise upon the borders are the monumental stones which mark the tombs of all the life which once dwelt upon a planet, and the thousand rifts in the solid floor commemorate the throes of the expiring world itself.

Yet possibly faint indications of change still manifest themselves in this planetary corse. But they are the changes of disintegration and decay. The prolonged and unclouded intensity of the solar rays succeeding the intense cold of the bi-weekly night would cause expansions and contractions of the rocky surfaces and rock-masses, which would impair their cohesion and weaken the supports of cliffs and walls. Students of the moon have occasionally fancied that certain changes had been noted. The little crater Linné, in the eastern part of the Mare Serenitatis, has been an object of intense interest in consequence of apparent variations in its aspects. It was first indicated by Riccioli. Lohrmann reported it 4½ miles in diameter, very deep, and under all illuminations distinctly visible. Mädler found it 6.4 miles in diameter. In 1866 Schmidt announced that the crater had wholly disappeared, though he had previously observed it as having a diameter of seven miles, and a depth of at least 1000 feet. Many observations were now made by others. Instead of Linné a white spot was found in nearly the same place, as supposed. Soon Schmidt noticed a little mountain in the middle of it, and later, several observers noted a circular depression in it, about six miles in diameter, while Secchi reported a crater half a mile in diameter in the middle of the white spot. During 1867, a slight depression was reported by some observers, and a crater-like pit by more. It was set down as not over one and a half miles in diameter. Huggins made it two miles, and Buckingham, a little later, three miles, outside measure. During 1868, the object was much studied, and it was generally

admitted to possess the appearance of a crater-like depression having an outside diameter of about seven miles, with a distance of three miles across from crest to crest, a depth of not over 500 feet, and a small central cavity less than half a mile in diameter. This general appearance has continued to the present.

The reality of these apparent changes has been much discussed. There are indications so strong, however, that different observers have not had their attention upon the same object, that a definite conclusion is unfortunately impossible. "Changes have actually occurred," says Neison, "or the description by Lohrmann and Mädler, as well as Schmidt's first declaration, was erroneous, since so great a change could be ascribed neither to variations of libration nor of illumination."*

The double crater Messier may also be mentioned as one in which changes are by some believed to have taken place in the relative size of the two craters.

Meantime another supposed change has been reported.† Hyginus is a deep crater 3.7 miles in diameter, intersected by a cleft 1,500 yards wide, running northeast 65 miles, and continuing southwest until its total length reaches 150 miles. Hyginus and the region about had been many times mapped and described before 1877, and no crater had been noted in all the neighborhood. But Dr. H. J. Klein, in May, 1877, reported in the region north of Hyginus, a large dark crater without a surrounding wall, but full of shadows. In June, he announced a dark encircling band which on the next day had disappeared. During some months following, the indications of a crater became more uncertain, and March 8, 1878, they had

*Neison: *Der Mond und die Beschaffenheit und Gestaltung seiner Oberfläche*, p. 133. A German translation of an English work which seems to be out of print.

†Neison, *Astronomical Register*, xvii, Nos. 201-3, 213. Also, "Anhang" of *Der Mond*, 417-40.

entirely disappeared. On the seventeenth, however, the crater was again distinctly visible. Since that date a multitude of observers have testified to its existence, and it now occupies a place, as Hyginus N, which a score of competent selenographers declare to have been destitute of any such form previously to the year 1877. In view of all the observations, Neison, who has systematically studied them, concludes that the observations made, especially during 1879, have rendered it probable, in the minds of most selenographers, "that finally, a real case of physical change upon the moon's surface has been practically demonstrated."*

Still more recently we receive reports of apparent changes in the crater Plato. Mr. A. Stanley Williams writes that of thirty-seven spots seen in the crater in 1869–71, six were not seen in 1879–82; while seven not seen during the first period were seen in the second. The mean visibilities of most of the spots observed in both series agree very closely, but eight show a decided variation in brilliancy. Among the light streaks in the crater some change was noted, particularly in one which was not seen at all during the first twelve months of the first period, and is now larger and brighter than others previously observed.†

Most of those who have admitted the reality of changes in the lunar craters have been inclined to ascribe them to a volcanic origin; but others have very reasonably questioned the validity of such a conclusion. The only supposable cause for such changes is the disintegration resulting from the extreme fluctuations of temperature already referred to.‡ These might effect the levelling of crater walls, and the partial filling of the cavity, if of

* Neison: *Der Mond*, 440.
† *Science*, 1, 311, Apr. 20, 1883, from *Observ.*, March 1.
‡ Proctor: *The Moon*, 380–2.

small dimensions; but it is difficult to conceive of changes thus originated as resulting in the obliteration and reappearance of the crater Linné, the variations in the relative diameters of the craters Messier, or the complete creation of the well defined crater Hyginus N. Much allowance must be made for the changing aspects of lunar objects under different kinds of illumination, much for the influence of the terrestrial atmosphere, and much for the various degrees of excellence in telescopes and the eyesight of observers. When all these deductions are made, perhaps the greatest actual changes noted will not be found to surpass the probable results of rock disintegration under extreme fluctuations of temperature.

The facts thus cited concerning the topography of the moon, make it clear not only that the physical conditions of the surface of that planet differ extremely from those of the earth, but also that its evolution has pursued a widely different course. We are, perhaps, in a position to reason out with a fair degree of probability the vicissitudes of the moon's physical history.

4. *Tidal Evolution of the Moon.* — Adopting the theory that the moon parted from the earth as a ring of fire mist and aëriform matter, and underwent spheration in the manner heretofore described, it becomes eminently probable that its axial rotation was not, at first, coincident with its orbital revolution. The tidal influence of the earth, however, caused the moon to assume the form of a prolate spheroid, having its longer axis directed constantly toward the earth, or very nearly so. But, as the moon, by hypothesis, presented different sides successively toward the earth, different portions of its substance successively underwent elevation into the tidal swell, and successively subsided at the ebb. Had the substance of the moon at this time been a perfect fluid, the tidal rise would have responded instantly to the terrestrial attrac-

tion, and the summit of the tidal swell would have been directed always exactly toward the earth. But, as the substance of the moon was not a perfect fluid, internal molecular resistances retarded the response to the earth's influence, and the tidal culmination was always a little behind the zenith position of the earth. In other words, the prolate axis formed a small posterior angle with the line joining the centres of the moon and the earth. The value of this angle, or the lagging of the geal tide, would be inversely as the fluidity of the moon's substance. The vertical dimension of the geal tide, notwithstanding its large absolute value, is so small compared with the diameter of the moon, and a fire-mist substance possesses so high a degree of internal mobility, that it is highly improbable that the lagging of the geal tide amounted to any considerable influence toward the retardation of the moon's rotation. Nevertheless, it must have acted as a real retardative cause on the moon's rotary velocity, and all the more so when the volume of the moon was greater than at present, and its distance from the earth was less.

In the course of time, according to our conception, the matter of the moon had cooled to the condition of a liquid globe. The tidal swell was now reduced in altitude, but the internal mobility of its parts was diminished. The angle of lagging was, therefore, considerably increased, and the tangential component * of the earth's attraction on the tidal protuberance operated more effectively as a retarding force. At the same time, any lack of homogeneousness in the density or viscosity of the parts would cause frictional resistances which, precisely on the principle of continental resistances to terrestrial tides, must have added something to the causes retarding the moon's rotation. Still, the geal tide was so small com-

* The reader will recall the exposition in a previous section (Part II, chap. ii, § 6.)

pared with the mass and volume of the moon, that the primitive rotation of that body was very slowly diminished. Had the moon suddenly become rigid, its prolate form would never have reduced its rotation to synchronism with its revolution, since if the prolate axis could be once moved far enough to make an angle a little exceeding 90°, with the line joining the moon and earth, the polar protuberances would induce as much accelerative action as retardative. But the moon was not rigid, and hence its nearest pole was continually in such position that the earth's attraction was continually retardative. During its liquid state, therefore, the rate of rotation must have been considerably diminished, though it is far from probable that the synchronistic stage was reached.

At length followed the stage of incrustation. Great complication in the action and interaction of the forces now ensued. This is the chapter of lunar history whose records are preserved in the strange and impressive forms remaining upon the visible disc of our satellite. The presence of a forming crust did not prevent the continuance of the geal and solar tides. These continually interrupted the continuity of the growing film. As a consequence, the incipient crust became a floe of floating fragments perpetually grinding against each other, perpetually cemented by the freezing lava which rose in the chinks and spaces between, and perpetually disrupted and rearranged by the disturbances of the recurring tides.* But as soon as rigidity began to appear in a continuous crust, most important changes were introduced in the conditions of tidal action. The solid film yielded less readily than the liquid beneath. Its rigidity caused it also to yield to a less extent. From the first cause the angle of lagging

* This conception of the influence of tides during the incrustive period of a planet's life has been expressed by me in *Sketches of Creation*, 1870, p. 51, and in earlier publications.

was greater in the crust than in the molten core. From the second cause the liquid pressed against the under side of the crust, tending to elevate it in a tide of the altitude due to the nature of the liquid. The liquid portion, for instance, tended to rise in a tidal swell to the height of A, Figure 57; but the more rigid crust rose only to B, and the liquid was restrained beneath it, pressing against it. This pressure was very greatly augmented by the greater lagging of the crustal tide. The mode of action is illustrated by the adjoining figure, 58, where E, E, E shows the direction of the earth, A represents the summit of the crustal tide, with a lagging angle A O C, and B represents the summit of the liquid tide if not restrained by the overlying crust, and having a smaller lagging angle, B O C. The portion of the liquid spheroid here shown external to the crustal spheroid is restrained within the crustal spheroid, and consequently presses with all the force due to the earth's attraction against the under side of the crust.

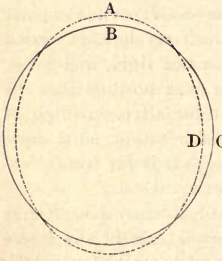

FIG. 57. ACTION OF THE INTERNAL TIDE AGAINST THE CRUST.

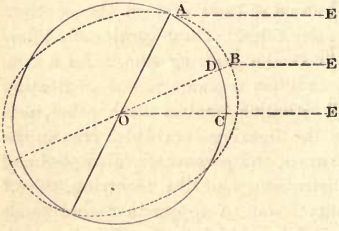

FIG. 58. EFFECT OF DISCORDANT LAGGING TIDES.

It would be impossible that the rocky lunar crust should attain, for a relatively long time, such soundness

and integrity as to resist fully the powerful tendency to rupture resulting from tidal actions. The periodical pressure exerted from beneath by the liquid tide would contribute to this tendency. Fissures, perforations, chasms in the crust, would be certain to result. Through these the pent-up liquid would pour at high tide, in lava floods of frightful magnitude. With the ebbing of the liquid tide, the fluid lava would retreat. The apex of the crustal tide now arrived and the crust experienced a tendency to remain above the liquid core. Insufficient rigidity to stand the strain would prevent the development of any real cavity beneath, but the crust would float with diminished pressure on the molten sea, and the fluid would be withdrawn from the openings. At the next tide of the liquid core, the matter would rise again through the vents and renew the vast overflow. Then it would again subside and the vacated perforations in the crust would become yawning pits illuminated by the glow of the lava sea revealed at bottom. These huge suspirations were continued as long as a lava tide remained to gush through the outlets of its prison. Long-repeated overflows of molten matter built up around the outlets enormous rims of frozen lava. The craters attained frightful depths which were revealed when the lava tide was at ebb. Frequently, after the crater rims had become greatly thickened, the fresh outflow of liquid matter ran down the external slopes like watery floods, and eroded the older lavas in drainage gorges. Again and again, the erosive action was repeated, and the surrounding region for many miles presented an aspect of vast and long continued denudation. Here were deep dark canyons winding to the lower levels; there were rugged bosses swelling above a sea of frozen lava; here were tower-like outliers of more ancient lava deposits which had escaped denudation, and there again, remained mountain masses of old lava, spreading their

bases over many a square mile, and lifting their attenuated summits many a thousand feet above the surrounding region.

It will be particularly noted that the vertical rise of the molten tide through the spiracles in the crust was not limited to the tidal elevation proper to an open, unrestrained surface. The tidal pressure accumulated against the restraining crust. The tidal swell, pressed back beneath the regions of unbroken crust, rushed with accumulated energy through the narrow vent when found. It was like the ten-fold tidal swell along the Hoogly or the Bay of Fundy. Hence it poured over the crater rims in torrents of astonishing depth. Hence, after the rims had been thickened to altitudes of thousands of feet, the rising flood could still attain their summits and lay down new deposits.

Here also, are disclosed adequate causes of explosive action. Sometimes, when the pressure of the subjacent tide had greatly accumulated, the solid resistances suddenly gave way. Fragments were thrown on high and columns of lava ascended probably hundreds of feet, as spouts of water rise at the end of a long "purgatory" on a rocky sea-coast, when the waves roll in and their gathered force spends itself in the free space above. These explosive occurrences must have scattered many huge fragments to great distances over the surrounding region; and, not impossibly, some of them were large enough to remain visible through terrestrial telescopes. The credibility of such occurrences is increased by the consideration that while the cohesive resistance of rock substances was the same as on the earth, and the force of rupture as great, the force of gravitation was only one-sixth as great as on the earth's surface.*

* The moon's mass is to that of the earth as 0125 to unity, and the relative attraction of this relative mass at the surface is inversely as the squares of the radii of the moon and the earth. Hence

On our own planet there have been outflows of molten matter which spread themselves in fiery seas over tens of thousands of square miles. Tidal action, probably, had a connection with these events. On the moon, where tidal action was a hundred and twenty times as violent, the molten outflow must have sometimes covered extensive areas, and cooled into wide and level plains. The older rugosities would be evenly buried, and the aspect would be that of an ocean. Here and there some of the greater saliences caused in former times would project like Alpine "Grands Mulets," or rocky islets, above the general level. Over the stiffening surface fell some of those projectiles hurled from the neighboring craters, and left their indentations on the pasty lava.

If the moon was derived from the mass of the earth, the constituents of water and air must have belonged to it, and it is eminently probable that some portions of these elements were left to enter into those unions which form water and air. I cannot entertain the conception of an original destitution of those substances on our satellite. There must have arrived a time, therefore, as in the history of the earth, when the condensation of aqueous vapors took place. There must have been an æonic storm. The rains must have fallen while the crust was still intensely heated. During this time the tidal swells and subsidences of the crust and molten interior were punctually alternating with each other. The rains were descending while the lavas were bursting through the crater vents. The rains descended on the lava seas. These meteoric events enormously exacerbated the violence of the lunar activities. The cooling of the exposed molten surfaces was accelerated, and the resistance to all movements

$$.0125 \times \frac{(3959)^2}{(1080)^2} = .1679 = \frac{1}{5.95},$$

which is, therefore, the moon's relative gravity, the influence of centrifugal force being neglected.

incident to tidal oscillations was correspondingly increased. Copious volumes of steam rose and condensed in clouds destined to perpetuate the storm and the reactions on the heated surface. The watery floods added their erosive work to that performed by the streams of lava. Both kinds of erosion were enfeebled by the feeble intensity of gravity on the moon.

But meantime, the crust was thickening, and the regions but little remote from the craters and the fresh lava streams, supported accumulations of water. The water was received in the pores of the rocks. In the progress of ages the crust was thickened to such an extent that all the water belonging to the moon had been absorbed. With the entrance of water in the rocks a new explosive agent was in readiness whenever the confined lava tides burst through new fissures, or in rising through the old ones encountered watery infiltrations. The crust was now some hundreds of miles in thickness. The first 133 miles would take in all the water belonging to the moon, on the assumption that its whole volume bore the same ratio to the volume of the earth's water as the moon's volume bears to the earth, and that the absorbent capacity of its rocks was the same as that of terrestrial rocks.* It is manifest, therefore, that the continued thickening of the crust would increase its porous capacity to such an extent as to absorb all the lunar atmosphere. It is worthy of special mention that the thickening of the crust upon a planet undergoing such copious eruptions of molten matter, would be more rapid than on a planet comparatively free from such eruptions. The increased rate of thickening would result both from the increased rate of general cooling, and from the addition of crustal layers upon the exterior.

* This results from an application of the formula given on a preceding page. The method of determining the constants used will be shown when treating of the future stages of the earth.

In the course of ages, the rigidity of the thickened crust became greatly increased. It yielded less to the tidal influence and the lagging angle was increased, and, therefore, the still fluid and tide-moved interior pressed with increased force against the under side. Perhaps many of the smaller vents had become sealed up in consequence of the permanent retention and final solidification of a portion of their lava contents, though the time had not yet arrived for solidification in the larger craters. Perhaps only the larger vents remained active; but their activity must have been somewhat enlarged. By and by the progressive reduction in the number of smaller vents resulted in a greatly increased pressure against the interior. The thickness and rigidity of the crust rendered it impossible that the pressure should find relief in any new or reopened vents of small dimensions. The pressure was felt beneath areas a thousand miles in diameter. The whole solid crust yielded. It rose, uplifted by the struggling, imprisoned tide. There was a focus of tidal pressure determined partly by the position of the tidal apex, and partly by the place of relative weakness in the crust. Here the supposed lava burst through. The crust was shattered as by a blow from beneath. Long radial fractures diverged for hundreds of miles from the new-made vent, and these were filled by lavas which were modern in comparison with those which had been rent. The existing accidents of the lunar surface sustained no perceptible ratio to the tremendous power which had burst a satellite. The fractures were rents in the general crust. They intersected older craters and mountains, as mere trifling incidents encountered in their course. After the cataclysm was past, a vast system of radial dykes covered the district that had suffered. In later ages, the different color of the material, or the marked salience of the dykes after subsequent erosion, caused them to appear more

brightly illuminated than contiguous portions, when exposed to the solar light and viewed from the earth. Somewhat such, perhaps, has been the history of those splendid star forms, Tycho, Copernicus, Kepler and others.

Perhaps the numerous canals or clefts depicted on the map of the moon belong to the same period of lunar evolution. They bear an analogy, certainly, to the great vein fissures and trap dykes which intersect so numerously terrestrial formations in certain regions. We may conceive that similar causes originated them. They are connected with the progressive refrigeration of the planet, the contraction of its mass, the unequal strains resulting from unequal rigidity of different parts, and the repeated stresses created by tidal oscillations.

While these great events were in progress, a powerful cause was in operation destroying the moon's axial rotation. Its action presented two modifications. *First*, the lagging of the tidal protuberance subjected it to the influence of a horizontal component of the earth's attraction. The effect must be such as heretofore explained when referring to the earth's diminished velocity of rotation. *Secondly*, the retral pressure of the internal liquid tide against the under side of the crust, as illustrated in Figure 57, was a more powerful cause of retardation. Finally, the period of rotation approximated the period of orbital revolution. The activity of physical work upon the moon was slackened. Longer intervals separated successive tides. The last overflows became more thoroughly chilled and torpid before new ones were poured over them. Now the pasty discharges rose slowly to the crater brim too viscid to leave readily the immediate border, and thus added the last courses to the grand rampart whose upbuilding had witnessed so many vicissitudes and so many revolutions. Probably the approximation to synchronism was gradual and continuous. Had the prolate moon been

rigid and still destined to a synchronistic state, there would have been a time when the pole of the longer axis, after passing the point turned toward the earth, would have swung back and repassed that point on the other side. After a large number of oscillations, the exact position which it now has would have been finally assumed, and from that mean position it could never change. But the moon was not completely rigid, and hence the rotary motion was never reversed or oscillatory, and the synchronistic position was attained by progressive differential retardation.

The æon of lunar violence endured only while the moon's rotary period was unequal to its orbital period. If the moon, while yet in a fluid state, possessed a non-synchronistic rotation, as in all probability was the case, such rotation continued long after the precipitation of water upon the surface. The tidal swell, as I have maintained, would not tend to retard rapidly the rotary velocity of a planet whose parts are entirely fluid. But if one part is rigid and another fluid, or if one part is less fluid than another, a relative translation of fluid parts must take place, and the friction of fluids and solids, or of more perfect fluids upon less perfect ones, under the influence of a tidally attractive body, would oppose that motion which determines local translation of the tidal wave. If the rotation is slower than the orbital motion, tidal friction will accelerate it. If the rotation is faster, it will retard it. This relation of more and less rigid parts exists upon an incrusted planet having a molten interior; and such a condition supplied, probably, the principal cause of the final synchronistic relation of the moon's motions.

If the moon, during the non-synchronistic æon had acquired the condition of a perfectly rigid or nearly rigid body, and possessed at the same time a prolate form, with the matter symmetrically disposed about the centre of

gravity, such rigid prolateness, as I have stated, would not tend to retard the axial rotation, but the satellite would revolve indefinitely about its shorter axis. From this we infer that the moon is not a rigid body, or that its synchronistic motions became established before rigidity was attained, or that its parts were unsymmetrically disposed around the centre of gravity in pre-synchronistic times. But the moon has never been a nearly rigid body, since the earth is not rigid, and the moon is composed of the same materials in a lower state of condensation; and while unsynchronistically rotating, its parts must have been symmetrically disposed about the centre of gravity, since no reason can be assigned why they should be otherwise; and hence the establishment of the moon's synchronous motions was not effected through the influence of an eccentric axis, but by slow degrees through the action of parts tidally moved either upon or beneath the resisting crust. That oscillation or libration which Laplace reasoned out was based on the supposition of a rigid globe, and it is not surprising, therefore, that even with modern observational precision, no librations have been discovered attributable to an actual oscillation of the prolate axis.

If, after the synchronistic stage of the moon had been reached, any fluids free to move, like water or air, covered any considerable part of its surface, they would gather themselves on the farther side of the moon, since, though the centrifugal force is slightly greater on the opposite side, the difference in the earth's attraction on the near and remoter sides is about twice as great as the difference in centrifugal tendencies.* The arrangement of elements

*The centrifugal force on the farther side is to that on the nearer side as 1.00904 to unity; but the earth's attraction on the nearer side is to that on the farther side as 1.01816 to unity. The difference in the terms of the ratio in the latter case is twice their difference in the former.

It is worthy of note, however, that in the process of the lengthening of the

or parts free to move would, therefore, be determined by terrestrial gravity. This fact renders undemonstrable the conclusion that water and air are absent from the moon, since the opposite side might be covered by a sea 432 feet deep * in the middle without reaching to the visible hemisphere; and a corresponding atmosphere might rest upon its surface. But the complete absence of all refraction, and all spectroscopic change in the stellar or solar light passing close to the limb of the moon, tends to negative the supposition of water or air, since if they existed on the remoter hemisphere, air and aqueous vapor would occasionally reveal themselves upon the moon's limb, especially at times when the lunar librations enable us to see beyond the limits of the mean hither hemisphere. It is, therefore, eminently safe to conclude, as we have, that the water and air of the moon have completely disappeared.†

lunar revolution there was an epoch when the moon's distance was such that differential centrifugal force was just equal to differential attraction exerted by the earth. This, according to my calculation, was when the moon's angular velocity was 1.398 times its present angular velocity, which implies a period of 19 days, 12 hours, 59 minutes and 29 seconds. At this epoch the fluids would have tended to distribute themselves equally around the satellite in spite of synchronistic motions. At a remoter epoch, with a still shorter revolution, the fluids would have tended to accumulate on the perigeal side.

* Were the earth non-rotating (as the moon is practically) and covered by a fluid, its tidal semi-axis would exceed its shorter semi-axis 58 inches, under the moon's influence. Hence if the moon's apogeal hemisphere were covered with water, it would be maintained, making no allowance for tidal yielding of the moon's body at a depth approximately of 38⅝ inches × 134 = 432 feet. This, strictly, is the height to which the geal tide would rise if the moon were covered with water and the moon's body were a rigid sphere.

It may be interesting to note that if the moon possesses no surface water, and its bodily rigidity is such that under geal tidal influence it yields one-half as much as a watery envelope would, then the protuberance at each extremity of the prolate axis is 432 × ½ = 216 feet.

† The foregoing views respecting the tidal evolution of the moon were written out substantially as here given in March, 1881. I had not then seen or heard of M. Faye's memoir on the geology of the moon, in the *Annuaire* for 1881, in which somewhat similar conceptions are set forth, and from which some citations are made in the present exposition of my views. M. Faye, however, denies the former presence of water or air on the moon, and denies all analogy between the ancient activity of the moon and terrestrial volcanoes.

According to the general theory here set forth, the crater phenomena of the

It would seem that lunar synchronous motions were attained while yet molten matter remained in the interior. The crater floors present the appearance of solidified lava pools. They conform to the general curvature of the moon's surface. But the thousands of feet to which we find these floors sunken, must bear a small ratio to the whole thickness which the crust had attained at the epoch of synchronism. Were the upper layer of the molten matter at any stage of the same density as the crust, the fluid would rise, in the case of a moon no longer tidally disturbed, to the general level of the lunar surface. If the fluid were lighter than the crust it would rise above this level; if it were heavier, it would come short of it. But the fluid was heavier than the crust, or the crust would have sunken. The depth of the lunar crater, therefore, is determined by the excess of density of the molten matter over the density of the superincumbent crust. When we reflect that this excess was very slight, we can easily understand that a crater-bottom sunken 10,000 feet implies a total thickness for the crust many times as great.

After the close of those tidal actions which wrought out the grand features of the moon's surface, there remained some concluding results of the long course of progressive refrigeration. *First*, the subsequent lowering of the general temperature of the crust increased its density, and consequently its pressure on the subjacent fluid; the fluid as a consequence, sought to rise through openings in the crust, or to burst through the weaker places of the crust. There were few places so weak or so recently consolidated as the crater floors; and in these the thinnest and the least

moon ought to be the most numerous in the region near the plane of the lunar orbit; but maps of the moon show them continuing with scarcely diminished frequency, quite to the vicinity of the selenographic poles.

Further, on lunar craters, the reader may consult M. Bergeron, *La Nature*, 1882, copied in *Pop. Sci. Monthly*, xxii, 495-7. illus., Feb., 1883; also H. J. Klein, *Petermann's Mittheilungen*, translation in *Observatory*, and reproduced in *Kansas City Review*, vi, 467, Dec. 1882.

supported parts were the central portions. Here, then, the residual fluid might most easily press through. *Secondly*, the same reduction of temperature resulted in contraction of the crust; and from this cause it pressed with increasing pressure upon the subjacent fluid. There was indeed, a time when the volume of that fluid was relatively large and its own abatement of temperature more than compensated for the increased constriction resulting from crustal contraction. But when the volume of fluid was greatly reduced and its protected situation caused much slower loss of heat, it seems probable that increase of crustal pressure would impel portions of the included fluid to seek chances of escape. *Thirdly*, the progressive thickening of the crust implies that liquid portions of lunar matter were continually becoming solid portions; that is, that some of the matter beneath the crust was becoming expanded and demanding more space. The action of these freshly solidifying portions upon the contiguous fluid furnished another source of pressure which made it necessary to seek relief. In these three causes, it seems to me, we have an explanation of those late exudations of lava which might have produced the central masses resting upon the floors of nearly all the lunar craters.* These have

*Since this was written I have read for the first time some remarks by Mr. W. Mattieu Williams, presented to the *Royal Astronomical Society*, March, 1873, in a paper on *The Origin of Lunar Volcanoes*. He refers to the cooling of "tap cinder" from puddling furnaces, which is received in stout iron boxes or "cinder bogies." "If a bogie filled with fused cinder is left undisturbed, a veritable spontaneous volcanic eruption takes place through some portion. *generally near the centre*, of the solid crust. In some cases this eruption is sufficiently violent to eject small spurts of molten cinder to a height equal to four or five diameters of the whole mass. The crust once broken, a regular crater is rapidly formed, and miniature streams of lava continue to pour from it; sometimes slowly and regularly, occasionally with jerks and spurts due to the bursting of bubbles of gas. The accumulation of these lava streams forms a regular cone the height of which goes on increasing." The circumstances under which these miniature cones are formed seem to be extremely analogous to those of the old crater holes on the moon after the attainment of the crustal quiescence due to the establishment of synchronistic motions.

been broken and dismembered by the movements attending the final stage of complete solidification of the satellite, as such final movements may also have fractured the crater rims and opened the thousand rifts in the general surface. They have also been subjected to whatever erosive action may result from the extreme fluctuations of temperature supposed to be experienced on the lunar surface.

These central monticles were therefore post-synchronistic, and the result of the last stages of lunar refrigeration. Since that epoch was reached, tidal and thermal forces being extinct, the lunar surface has presented only an unchanging scene of mighty desolations, oppressive stillness and dead stagnation.

5. *The Atmospheric Factor in Lunar History.*—On the ground of nebular theory, the moon in segregating from the earth, whether through annulation or rupture, must have received a portion of atmosphere or the elements of such an envelope. As to the relative amount of atmosphere, we can scarcely make any other assumption than that its mass bore nearly the same ratio to the earth's present atmosphere as the moon's mass bears to the earth's. The mass of the lunar atmosphere would be one factor in the determination of its relative pressure on the lunar surface. The amount of surface on which it presses would be another factor. As the moon's surface is greater in comparison with the earth's than the moon's mass in comparison with the earth's, this difference would diminish the relative pressure on each unit of lunar surface. The earth's mass is 80 times the moon's, but its surface is only $13\frac{1}{2}$ times the moon's. Aside from difference in atmospheric masses, pressure would be inversely as the areas of the moon and earth; or what is the same thing, inversely as the squares of the radii of the two bodies. Again, with equal atmospheric masses and equal planetary surfaces, the relative intensity of gravity would be another

factor in determining the atmospheric pressure on a planet. When, therefore, we multiply together the ratio of the masses of the moon and earth, the inverse ratio of their surfaces and the ratio of the intensities of gravity on the two bodies, we find the relative atmospheric pressure to be .02787 at the time when its normal proportion of the atmospheric medium was still present.* This result is somewhat surprising, and leads to interesting inferences. The barometric column stood at .836 of an inch, which implies an atmospheric pressure too insignificant to constitute a positive factor in a planet's genetic development; though it implies the virtual absence of those terrestrial actions which depend on the terrestrial atmosphere, and thus enables us to trace the divergence between the histories of the two bodies.

A barometric column of five-sixths of an inch corresponds to a terrestrial altitude of 17.7 miles, or over three times the height of the Himalayas.† Under such a pres-

*We may embody these principles in a general formula. If M, S, R, g and P represent the mass, surface, mean radius, gravitational intensity and atmospheric pressure of the earth; and m, s, r, g' and p, the same constants for any other planet, then

$$p = \mathrm{P} \cdot \frac{m}{\mathrm{M}} \cdot \frac{\mathrm{S}}{s} \cdot \frac{g'}{g} = \mathrm{P} \cdot \frac{m}{\mathrm{M}} \cdot \frac{\mathrm{R}^2}{r^2} \cdot \frac{g'}{g} = \mathrm{P} \cdot \frac{\mathrm{R}}{r} \cdot \frac{\rho'}{\rho} \cdot \frac{g'}{g},$$

where ρ and ρ' represent planetary densities respectively.

In the case of the moon $\frac{m}{\mathrm{M}} = .0125$, $\frac{\mathrm{S}}{s} = 13.471$ and $\frac{g'}{g} = .1655$.

And $p = .02787$ P.

If we take the mean height of the mercurial column as the measure of P, then the normal mean height of the barometer on the moon must have been

$h = 30$ inches $\times .02787 = .836$ inch.

†The formula for the barometric calculation of heights in the latitude of Great Britain is

$h = \log \frac{\mathrm{P}}{p} \times [60360 + (\theta - 32°)\ (122.68)]$ (Maxwell: *Theory of Heat*, 222; see also, Deschanel: *Natural Philosophy*, Everett's ed., 164), where P and p are the pressures at the upper and lower stations, and h is the height in feet for a temperature t on Fahrenheit's scale. Here we may assume the temperature at 32° Fahr. Hence the second term in the second factor reduces to zero and we have

$$h = \log \frac{\mathrm{P}}{p} \times 60360.$$

In the present case P = 30 inches and $p = .836$; hence

$h = 93{,}854.669$ ft. $= 17.77$ miles.

sure the boiling point of water would be at 37½° Fahr.*—a result of extreme interest. The first inference to be deduced from this atmospheric tenuity is the comparatively advanced stage of cooling attained before the precipitation of water began. The second is the very limited duration of the period of sedimentation, which would, indeed, be further slightly shortened by the commencement of ice-formation at a temperature above 32°.†

The third inference is the low altitude at which the clouds must have been borne in so thin an atmosphere, since only the lightest cirrus clouds are borne by the terrestrial atmosphere at an altitude of about eight miles, or one-half that required for the tenuity of the lunar atmosphere. In short, it may even be doubted whether vapor would be formed on the moon, even close to its surface, of sufficient density to cause rain. Not unlikely, the only precipitation was a cold fog resting on the surface of the planet. In this view, there was no erosion by waters, and no sedimentation; and the moon's water was absorbed simultaneously with the air. With a little further cooling of the planet, the lunar solidifying temperature of water was reached; and thereafter it was revealed in the liquid state only in situations when the sun's direct rays caused some elevation of temperature above the mean. A fourth inference from the existence of an atmosphere of such extreme tenuity, and holding so little vapor, concerns the influence of the sun's radiations on the lunar surface. It is well understood that the atmospheric and vaporous

*By Soret's formula (Deschanel: *Nat. Phil.*, Everett's ed., 338),

$$h = 538\,(212° - t),$$

where t = the temperature on Fahrenheit's scale at which water boils at the height h in feet. Whence

$$t = 212° - \frac{h}{538}.$$

In the present case $h = 93{,}854.669$ ft., $\therefore t = 37\frac{1}{2}°$ Fahr.

†See Maxwell: *Theory of Heat*, 176-7, and the authorities there cited. See also, this work, pp. 270-2.

envelope of the earth absorbs a large percentage of the sun's thermal radiations, and partially restrains, also, the escape from the earth of such heat as succeeds in reaching it. The lunar condition here considered, therefore, admitted a higher intensity of solar heat, but at the same time, all situations with free radiation sent the heat back with correspondingly increased rapidity. The situation is approached when we ascend to the summit of a very high mountain. The sun's rays are, indeed, hotter, but the terrestrial radiation is augmented in still greater ratio, and the temperature is lower. Rising through the atmosphere we remove successively some of the protective wrappings which keep the earth warm. Professor S. P. Langley has reported some observations made on the summit of Mount Whitney, a peak of the Sierra Nevada in southern California, attaining an altitude of 13,000 feet. Here the solar rays heated to the boiling point some water in a copper kettle covered with two pieces of window glass to prevent radiation.* From these and other observations, it appears that our atmosphere at sea level absorbs about one-half of all the radiant solar energy —luminous, thermal and actinic —and that the selection of rays to undergo absorption is such that the white light reaching us, formed of the united rays of certain wave lengths, is not the color of the light resulting from the complete union of all the solar rays, but contains far too little of the blue and violet rays. Hence, Professor Langley concludes, the color of the sun seen from a point beyond our atmosphere would be not only bluish, but positively blue. This, we must conclude, therefore, is *the*

* S. P. Langley: *The Mt. Whitney Expedition*, Nature, xxvi, 314-7. Further, on the "selective absorption" of the atmosphere, see his paper before the British Association, 1882, in *Nature*, xxvi, 586-9, Oct. 12, 1882, republished in *Amer. Jour. Sci.*, III, xxiv, 393-8; also a memoir in *Amer. Jour. Sci.*, III, xxv, 169-96, March, 1883. Detailed results of the Mt. Whitney Expedition are to be published by the "U. S. Signal Service."

color of the sun viewed from the moon, either after the complete absorption of its atmosphere, or even while retaining its normal atmosphere in such a state of tenuity as has been indicated. In open space the rapidity of radiation, according to Professor Langley, must be so great that in spite of the intensity of the sun's rays, a suspended body would sink to a temperature below —50° Fahr. This, then, from this point of view, must be the upper limit of the surface temperature of the sunny side of the moon; and thus the fluctuations of temperature during a lunation must be vastly less than Lord Rosse and others have calculated; and the modern changes due to thermal fluctuations are diminished correspondingly. During the whole lunar lifetime, even while the normal amount of atmosphere remained on the moon's surface, the temperature, after the formation of a cold crust, must have remained nearly at —50° Fahr. or below.* Not only water, therefore, but mercury and other substances known to us as liquids or gases, existed on the moon only as solids. In this view, the conception of aqueous erosion and sedimentation is entirely excluded, save so far as the primitive inherent heat of the satellite maintained at the surface a liquefying temperature. At the time when the residual effect of solar radiation, inherent heat and lunar radiation produced a surface temperature, say between 34° and 37° Fahr., water may have rested on the lunar surface during the lunar day, but it would be consolidated during the lunar night. As some of this water occupied the pores of the rocks, here was a cause of considerable disintegration, so long as the water had not sunken beyond the reach of the thermal fluctuations. In any view,

*This statement must be modified so far as the retention of the moon's water in the atmosphere would increase absorptive effects experienced by the sun's rays. The ratio of aqueous vapor to the whole atmosphere was much greater than the ratio of aqueous vapor in the terrestrial atmosphere, and rose to the ratio existing on our planet before primeval precipitation began.

however, there seems little ground for inferring that the process of sedimentation was an important factor in any stage of lunar development.

Thus, an attentive consideration of the divergences between lunar and terrestrial conditions reveals the interesting fact that lunar history must have presented characteristics widely divergent from those of terrestrial history; and in this divergence, the tenuity of the moon's atmosphere has performed a part quite comparable with the energetic work of the tides.

§ 3. MARS.

1. *Phenomena of Mars and their Interpretation.*— This planet has, in relation to the earth, a surface of .2828, a volume of .1470, a mass of .1108, a density of .7537 and an intensity of gravity at the surface of .3917. Its lower density may reasonably be attributed to its smaller mass. The length of planetary periods on Mars would be, according to the method of calculation previously employed,* about two-fifths as great as on the earth. Hence, if the earth's incrustation began fourteen million years ago, Mars reached the earth's present condition in less than five and a half million years after incrustation began. If Mars and the earth began incrustation at the same epoch, Mars had reached its habitable stage nine and a half million years ago, or at the beginning of Eozoic Time. This expresses the relative rates of evolution of the two planets independently of any assumed nu-

$$*T = \frac{H}{\Delta} = \frac{.1108}{.2828} = .3917 = \frac{1}{2.553}.$$

It will be noticed that, as in the case of the moon, the same number expresses the relative length of the planetary period, and relative gravity at the planet's surface. This is because relative gravity varies as the mass and inversely as the square of the radius, and the relative length of the planetary periods varies as the mass and inversely as the surface; that is, as the mass and inversely as the square of the radius. These calculations take no account of centrifugal force on the several planets.

merical value of the earth's age, if we accept the table of time ratios previously given.

According to our theory, Mars is an older planet than the earth; and for this reason, as well as its more rapid rate of senescence, it should be much further advanced in planetary life than the earth. The stage of atmospheric absorption, however, if we adopt the popular view, seems not yet to have been attained; and astronomers used to speak confidently of extensive watery areas on the surface. Moreover, we witness polar phenomena which seem to indicate alternate advance and retreat of the polar ice caps. On the whole the physical phenomena have been understood to indicate a planetary stage not very different from that attained by the earth. But we may doubt, not alone on theoretical grounds, but from the admitted fallacy of similar opinions formerly entertained concerning the moon, whether the diversified shades of color seen on Mars imply the real existence of surface water. An inspection of a map of Mars shows a distribution of light and dark shades which is very improbable, viewing them as areas of land and water. There are too many and too extensive long and slender arms of the sea, and these do not show any conformity to any fundamental planetary cause. The longer axes tend rather to be transverse to the meridians than coincident with them. If the white areas about the poles are really snow-covered surfaces, as Sir William Herschel first suggested, it might be inferred that the climates are quite comparable to those of the earth. The greater inclination of the planetary axis to the orbit, by the amount of 5°, would tend to diminish the extent of both polar ice caps.* Although the alternate advance and retreat of these white areas, with the changes in the seasons, is confirmatory of the prevalent opinion respecting their natures, this must still be regarded a question under con-

*Part II, ch. ii, § 9, 3.

sideration. The ruddy color of Mars is generally ascribed to a dense atmosphere; but surely, if such an atmosphere existed, clouds of aqueous vapor must sometimes obscure some portions of the disc, and sometimes, indeed, the whole of it. In fact, the existence of polar snow implies the existence of clouds. These have never been noted, even in the polar regions of the planet. Father Secchi attributes a thin atmosphere to Mars and states that white spots are occasionally seen on his disc, which may be regarded as clouds, and that whirlwind movements may sometimes be seen in them.* But these statements in view of the results of calculations here adduced may well be distrusted. There is much reason, therefore, to doubt whether the popular interpretation of the visible phenomena of Mars is the correct one.†

2. *Tidal and Atmospheric Influences on Mars.*—The tidal efficiency of the sun on the surface of Mars is .4306 relative to his tidal efficiency at the distance of the earth. The whole vertical fluctuation of the solar tide, therefore, on the surface of the water-covered planet would be fourteen inches, assuming that the conditions are otherwise such as enable the moon to cause upon the earth a tidal fluctuation of fifty-eight inches.‡ The tidal influence of

* Secchi: *Le Soleil*, ii, 392.

† Prof. Elias Loomis, nearly thirty years ago, advanced the opinion that the equatorial region of Mars must have a mean temperature at 11° Fahr. below zero, and the poles, 51° below zero, and raises the question how the Martial snow caps could ever diminish under such temperatures. (Loomis, *Proc. Amer. Assoc.*, 1855, 74-80.)

‡ Employing the notation used when treating of the moon (p. 384), and denoting by f the sun's tidal efficiency at the earth and by f' its efficiency at a different distance, the general formula becomes

$$t = \mathrm{T} \cdot \frac{\mathrm{M}}{m} \cdot \frac{f'}{f} \cdot \frac{r}{\mathrm{R}} \cdot \frac{g}{g'}.$$

But the tide-producing body being the same in the two cases here compared, $\frac{\mathrm{M}}{m} = 1$. Also, here, $\frac{f'}{f} = .4306$, $\frac{g}{g'} = \frac{1}{.3857}$ and $\frac{r}{\mathrm{R}} = \frac{21881}{39685}$, whence $t = .6122\ \mathrm{T}$; and when $\mathrm{T} = 58 \times \frac{2}{5} = 23.2$ inches,

$$t = 23.2 \times .6122 = 14.2 \text{ inches.}$$

the earth upon Mars is entirely insignificant, not amounting, at the perigee of Mars, to a total fluctuation of more than one four-hundredth of an inch. The satellites of Mars, though in proximity sufficiently close to acquire marked tidal efficiency, possess too little mass to exert any important influence. The inner satellite, Phobos, if having a diameter of twenty-five miles, a distance of 6,000 miles from the centre of its primary, and a density equal to that of the primary (which is probably too great), would cause upon the ocean-covered surface of the planet a total linear tidal fluctuation of only ten and a quarter inches according to my calculation.* The evolution of

*It will be best, with a view to future applications, to deduce a rough general formula for the linear value of the tidal fluctuation on any tide-bearer, produced by any tide-mover.

1. *Symbols referring to tide-bearer.*

Let T = fluctuation of tide on the earth produced by its tide-mover,
D = distance of the earth's tide-mover,
R = radius of the earth,
M = mass of the earth,
g = intensity of gravity on the earth.
t = fluctuation of tide on any other tide-bearer,
d = distance of the other tide-bearer from its tide-mover,
r = radius of the other tide-bearer,
m = mass of the other tide-bearer,
g' = intensity of gravity on this tide-bearer.

2. *Symbols referring to tide-mover.*

m' = mass of tide-mover acting on the earth,
μ = mass of the other tide-mover.

Then
$$t = T \cdot \frac{D^3}{d^3} \cdot \frac{r}{R} \cdot \frac{\mu}{m'} \cdot \frac{g}{g'},$$

where $\frac{D^3}{d^3}$ = tidal efficiency depending on distance,

$\frac{\mu}{m'}$ = effect depending on mass of tide-mover,

$\frac{r}{R}$ = effect depending on radius of tide-bearer,

$\frac{g}{g'}$ = effect depending on intensity of gravity.

But $g' = g \cdot \frac{m}{M} \cdot \frac{R^2}{r^2}$, and by substitution,

$$t = T \cdot \frac{D^3}{d^3} \cdot \frac{r^3}{R^3} \cdot \frac{M}{m} \cdot \frac{\mu}{m'}.$$

Mars, therefore, has proceeded without any considerable interposition of tidal forces.

Supposing, as I have done in the case of the moon, that the Martial atmosphere bore the same ratio to the mass of the planet as the earth's atmosphere to the earth's mass, the density of the planet's atmosphere would be .138 relative to the earth's atmospheric pressure. This corresponds to a barometric altitude of 4.14 inches.* Hence the atmospheric pressure on Mars would be only such as our atmosphere possesses at an altitude of 9.83 miles above sea level.† This result discloses at once a wide contrast between the surface condition of Mars and that of the earth, even during the period while Mars retained its normal amount of atmosphere. The thermal effect of the sun's rays would be greatly diminished; and, when we reflect that the sun's mean intensity at the distance of Mars is less than half that at the earth, it becomes apparent that the temperature at all seasons must be considerably below that of the earth. With the atmospheric pressure so low, we find that water would boil at the temperature of about 115° Fahr.‡ Hence precipita-

This formula is identical with that deduced from the general expression for a tide (p. 229), but the *rationale* is here made more intelligible.

In the present case, if we make comparison with the fluctuation of the lunar tide on the earth, T = 58 inches; $\frac{D^3}{d^3} = \frac{(240000)^3}{(6000)^3} = 64000$; $\frac{r^3}{R^3} = (.5303)^3$; $\frac{M}{m} = \frac{1}{.1081}$; $\frac{\mu}{m'} = \frac{(25)^3 \times .700}{(2160)^3 \times .607}$.

And $t = 10.24$ inches.

* Using the formula given in the discussion on the moon, we have

$$\frac{m}{M} = .108, \frac{S}{s} = \frac{(3963)^2}{(2181)^2}, \text{ and } \frac{g'}{g} = .387,$$

Whence $p = .138$ P.

If we take the measure of P as the mean height of the mercurial barometer, $p = 30$ in. $\times .138 = 4.14$ inches.

† Using, as before, the formula for barometric measurement of altitudes,

$$h = \log. \frac{30}{4.14} \times 60360 = 51{,}916.9 \text{ ft.} = 9.83 \text{ miles.}$$

‡ From Soret's formula, as before,

$$t = 212° - \frac{51916.9}{538} = 115°.5 \text{ Fahr.}$$

tion and sedimentation did not begin on this planet until cooling had advanced a hundred degrees further than on the earth. As solidification of water, under diminished atmospheric pressure, took place at a slightly higher temperature than on the earth, the range of temperature within which denudation and sedimentation could have been carried on was greatly contracted. The attenuated atmosphere also promoted escape of heat from the planet. These considerations all point to a more rapid attainment to successive planetary stages, and lead definitely to the conclusion, indicated on other grounds, that Mars is *not* lingering in the terrestrial stage, but has lost all water and atmosphere, and advanced far toward the lunar stage of total refrigeration.

§ 4. VENUS AND MERCURY.

1. *Venus.*—Next to Mars, Venus is generally supposed to sustain closest planetary relations to the earth. Its diameter is .9475; its volume, .855; mass, .875; density, 1.03, and the intensity of gravity at the surface, .982, the earth's corresponding values being unity. The relative intensity of solar radiations at Venus is 1.913, or nearly twice that at the earth's distance. The relative length of the planetogenetic periods, according to principles previously explained, is .977. Solar tidal efficiency is 2.643, and the relative linear height of the solar tide is 2.543, which, on a water-covered planet, implies a total fluctuation of 7.37 feet. The pressure of the atmosphere, calculated from ratio of mass and surface, is .9595, which corresponds to a mean barometric height of 29.78 inches, an elevation on the earth of 192.91 feet above sea level, and a boiling point of 211°.64 Fahr. In every particular, therefore, Venus reproduces nearly the conditions of the earth, except those which arise from greater proximity to the

sun — intensity of heat, light and tidal action, and these are not very widely different. We may therefore suppose a planetary history not far divergent from that of the earth. The surface of Venus is stated by some observers to be densely veiled in clouds.

The nebular theory implies an increasing density toward the centre of the nebula, not only in consequence of internal pressure, but probably through the gravitation of the denser constituents of the nebular mass toward the centre. The first cause would not operate after the separation of the planetary mass. Density due to superincumbent pressure would now depend on the radius of the planet and the coefficient of condensation of the material under pressure. As Venus has a shorter radius and higher density, there is manifestly a certain amount of density due to the fact that the proportion of denser materials is somewhat greater in Venus than in the earth,* and this is as it should be. This subject, however, is connected with what follows.

The excess of solar heat upon Venus must have exerted some influence upon the evolution of the planet. The rate of cooling was somewhat impeded, and this effect was relatively greatest in the later and cooler stages. After the epoch of aqueous precipitation, the solar heat efficiently reinforced the inherent heat of the planet in promoting copious evaporation and cloud formation. When the inherent heat had so diminished that its surface influence became similar to that of the earth in historic times, the excessive heat of the sun still maintained a copiousness of evaporation double that upon the earth. As long as this rate of evaporation could be maintained, there must have

* If the condensation of solids were proportional to pressure, as in gases, the density in this case would be .9519, and the excess of the actual density would be .078. But the condensation in solids is in a lower ratio than the pressure, and this excess is too great.

been also, a double amount of precipitation. But the effect reacted on the cause. The clouds formed prevented the free access of heat to the planet, and the amount of cloud formation and consequent precipitation was proportionally diminished. The final adjustment of these causes and effects determined a ratio of cloudiness and precipitation much greater than on the earth, but somewhat less than twice as great. Meantime the cloudy envelope of the planet must be nearly complete and permanent. I know of no ground for negativing the assumption that the vaporous veil which protects Venus is of such density as to admit about the same amount of heat and light as is received by the earth. The conditions on the planet's surface may easily be analogous to those upon the earth on a thinly clouded day. But while the cloudy envelope screens out solar heat to the terrestrial standard, it restrains, also, the process of radiation from the planet. Consequently the depression of temperature during the night is relatively less. Further, supposing the axis inclined toward the plane of the orbit, seasonal periods mark the year. But, in the winter season, the diminution of the sun's intensity simply clears the atmosphere to a corresponding extent. The winter season is therefore the season of clearest skies.

If Venus is surrounded by a perpetual mantle of clouds, astronomers have never seen the body of the planet. Its diameter is therefore less and its density greater than have been calculated; and we have so far confirmation of our deductive conclusion that Venus possesses a greater proportion than the earth of the heavier substances of the primeval nebula. In this view also, the diameter of the planet is not accessible to measurement; and the determination of the rotary period will not be accomplished. There might be produced a belted arrangement of lighter and darker clouds in the equatorial region; but no fixed

feature is likely to afford the means of ascertaining the length of the day.*

2. *Mercury.*—Passing to Mercury, we find a planet whose relative diameter is .3858; surface, .1489; volume, .0574; mass, .065; density, 1.12; solar intensity at perihelion, 10.58; at aphelion, 4.59, with a mean of 7.58.† Its relative intensity of gravity is .432, which is only equal to that exerted by the earth at the elevation of 2,066 miles above its surface. The relative length of the planetary periods, is therefore, .4366; mean solar tidal efficiency is 17.24, and the mean linear fluctuation of the solar tide in an oceanic envelope would be 15.41 or 29.79 feet. At perihelion the solar tidal efficiency is 34.39, and the relative linear fluctuation in an oceanic envelope is 31.71, which implies an actual fluctuation of 66.49 feet. This tidal influence is experienced every 88 days. The tidal influence of Venus, when nearest Mercury, compared with the lunar tide on the earth, would be only .000068, or about four thousandths of an inch. The pressure of the atmosphere should be .1882, corresponding to a barometric height of 5.646 inches.‡ This pressure is attained on the earth at an elevation of 8.29 miles, and implies a boiling point for water of 130°.8 Fahr. As Mercury's percentage of atmosphere is probably less than the earth's,§ the results just given are probably too large. Mercury, therefore, differs from the earth to a very marked extent, not only in those points connected with greater nearness

* Cassini, guided by certain supposed spots, calculated the rotation period as a little less than twenty-four hours. Schröter, by observations along the "terminator," believed that he had fixed the period of rotation at .973 d. This method implies the existence of high mountains on the planet.

† The orbit of Mercury has an eccentricity thirty times that of Venus and twelve times that of the earth.

‡ Mr. W. Mattieu Williams makes it four and one-fourth inches, but his method of calculation is not indicated.—*Current Discussions in Science*, Humboldt Library, No. 41, p. 20.

§ Mercury has sometimes been represented by observers as covered by a dense atmosphere loaded with clouds.

to the sun, but also in everything connected with smaller mass.

We have here a further and much more decisive exemplification of the theoretical principle that heavier matter accumulated about the centre of the primitive nebula, since, while Mercury's diameter is only three-eighths as great as the earth's, its density is nine-eighths as great. Aside from the influence of solar heat in retarding Mercury's developmental progress, we might probably regard this planet as advanced to a habitable stage.

In consequence of the powerful tidal action exerted, Mercury must have undergone an incrustive history somewhat analogous to that of the moon, but very much less violent. Aside from any consideration of the presence of water, it seems likely that its surface was powerfully marked by crater formations and an extensive system of fractures. But water was present, though probably in less proportion than on the earth, and some erosion and sedimentation have taken place, if we can admit the solar heat moderate enough to allow aqueous precipitation. During the day, with the solar intensity from $4\frac{1}{2}$ to $10\frac{1}{2}$ times that experienced by us, it is scarcely credible that rain should fall except in situations protected by vapors. These would exist even during the day, and most copiously in the perihelion period; for in spite of the sun's intensity upon the exposed surface of the clouds, the rapidity of radiation would probably preserve a temperature low enough for condensation. During the night, however, condensation would be vastly more copious, and hence the night side of the planet would be deeply veiled, and also deluged with rain. A violent thunder storm followed sunset around the planet continually. Thus all sides of the planet were enveloped in cloudy vapors, hovering, however, close to the surface. This condition of things began when the inherent heat had sufficiently abated to

permit a temperature of 131°. I know of no advanced condition which should prevent its continuance to the present epoch. The powerful tidal action experienced by Mercury has greatly retarded its primitive axial motion, and increased its distance from the sun. No surprise would be occasioned by the proof that the planet has already attained to synchronistic motions. Its retirement from the sun has been accompanied by a growing infrequency of perihelion positions and a diminishing intensity of all the solar influences.

Mercury, therefore, as well as Venus, is screened from telescopic observation, and nothing can be known of its actual diameter or period of rotation.* Owing, however, to the thinness of its atmosphere, and the low altitude of the clouds, the real density of the planet cannot be much greater than has been calculated.

§ 5. JUPITER.

1. *Physical Relations.*—This planet, in consequence of its enormous mass, presents physical conditions immensely different from those of the earth. Compared with the earth, Jupiter has a diameter of 11.06; a surface of 117.9; a volume of 1279.412; a mass of 308.990; a density of .242; a force of gravity at the equator, making allowance for centrifugal effect, of 2.254.† As the rotation period is 9 hours 55 minutes and 34 seconds, the equatorial centrifugal force is 63.13 times as great as on the earth, and

* Schröter's observation, giving a day of twenty-four hours, five minutes, has not been confirmed by other astronomers using far superior instruments.

† These data are taken from the *Annuaire du Bureau des Longitudes*, 1881. They differ somewhat from those given in the *Encyclopædia Britannica;* and both differ somewhat from Newcomb's tables in his *Popular Astronomy*. It will be found that the results of calculations in this chapter are in some cases inharmonious with each other, in consequence of employing data in different cases from different authorities.

diminishes materially the effective force of gravity.* Disregarding the effects of rotation, the relative surface gravity of Jupiter is 2.619.† This is therefore the force of gravity at the poles, neglecting the effect of oblateness. In any other latitude the actual intensity of gravity is given by diminishing the stationary gravity by the vertical component of the centrifugal force in that latitude. The centrifugal force at the earth's equator is equivalent to 0.1112 feet per second,‡ and that on the equator of Jupiter

*Letting r, f, t and v represent the mean radius, equatorial centrifugal force, rotation period and equatorial velocity of Jupiter, and R, F, T and V the same in respect to the earth, we have by a familiar dynamical principle $F = \frac{V^2}{R}$ and $f = \frac{v^2}{r}$. Therefore $F : f :: \frac{V^2}{R} : \frac{v^2}{r}$ and $f = F\frac{v^2}{V^2} \cdot \frac{R}{r}$. But $v : V :: \frac{r}{t} : \frac{R}{T}$ $\therefore$ $\frac{v^2}{V^2} = \frac{T^2}{t^2} \cdot \frac{r^2}{R^2}$; and, substituting, $f = F \cdot \frac{T^2}{t^2} = \frac{r}{R}$. By putting T = 86,164 seconds, t = 35,720 seconds, R = 3959 miles, r = 43,000 miles and F = 1, we obtain f = 63.13. The vertical component of the centrifugal force in any latitude λ, is therefore $f' = 63.13 \cos^2 \lambda$, and for the latitude of 45°, f' = 31.57.

†Since surface gravity is directly as the mass and inversely as the square of the radius, we have, adopting notation similar to the last, $g' = g\frac{m}{M} \cdot \frac{R^2}{r^2} = 2.619$.

Taking the oblateness of Jupiter as $\frac{1}{16.88}$, and the mean diameter as 84,843 (*Encyc. Brit.*), equatorial gravity is reduced to .9601 of the gravity computed on the assumption of a spherical planet. This reduces the force of gravity on Jupiter's equator to $2.619 \times .9601 = 2.515$. For, if D and d represent the transverse and conjugate diameters of the oblate spheroid, and r, the radius of the equivalent sphere,

$$\tfrac{4}{3}\pi r^3 = \tfrac{1}{6}\pi D^2 d; \text{ whence } D^2 \times \frac{8 r^3}{d}.$$

But, as $\frac{D - d}{D} = \frac{1}{16.88}$, $d = \frac{D}{1.063}$, and substituting,

$$D^3 = 8.504 r^3, \text{ and } D = 2.041 r = 86{,}590 \text{ miles};$$

whence $d = \frac{8 r^3}{(86{,}590)^2} = 81{,}460$, and $D - d = 5130$ miles.

Finally, if g' and g'' represent equatorial gravity on the sphere and spheroid, $g'' = \frac{g' r^2}{\frac{1}{4} D^2} = \frac{4 \times (42{,}421.5)^2}{(86{,}590)^2} = .9601$ as above.

‡The equations $F = \frac{V^2}{R}$ and $V = \frac{2\pi R}{T}$ give us $F = \frac{4\pi^2 R}{T^2}$.

Whence, taking the mean radius of the earth at 20,923,900 feet, according to Sir John Herschel, F = .1112 feet per second. Whence the equatorial centrifugal force on Jupiter is $.1112 \times 63.13 = 7.025$. Or, we may obtain this result from the independent formula,

$$f = \frac{4\pi^2 r}{t^2} = \frac{4\pi^2 \times 43.000}{(35720)^2} = 7.025.$$

is 63.13 times as much, or 7.02 feet. As the space through which a body falls in a given time is proportional to gravity, a body falling 16.1567 feet in one second on the earth's equator, making no allowance for centrifugal force, or 16.0455 under the actual centrifugal force, would fall, on Jupiter's equator, 42.3 feet, making no allowance for centrifugal force, or 35.3 feet under the actual centrifugal force on that planet.

When we attempt to reach some conception of the relative length of planetary periods on Jupiter, it becomes apparent that the great present disparity of densities renders it necessary to reduce Jupiter to the earth's density, or to reduce the earth to Jupiter's density. Now, if Jupiter had the density of the earth, his mean diameter would be 53,530 miles;* his relative surface, 45.7, and the relative length of his geological periods, 6.761 times the length of the corresponding periods on the earth.† If, on the contrary, the earth were reduced to the density of Jupiter, its diameter would be 12,721 miles and its surface $\frac{1}{4\,6}$ that of Jupiter, or 2.581 times its present surface.‡

* Employing notation as before, $\frac{m}{M} = \frac{r'^3}{R^3}$, densities being the same. Hence

$$r' = \sqrt[3]{\frac{m\,R^3}{M}} = \sqrt[3]{\frac{308.99 \times (3959)^3}{1}} = 26{,}765 \text{ miles.}$$

† Employing the same principle as heretofore,

$$T = \frac{m}{s} = \frac{308.99}{45.7} = 6.761.$$

‡ Since on this supposition $\frac{m}{M} = \frac{r'^3}{R'^3}$,

$$R' = \sqrt[3]{\frac{M\,r'^3}{m}} = \sqrt[3]{\frac{1 \times (43000)^3}{308.99}} = 6360.44 \text{ miles.}$$

Further, the earth's relative surface on this supposition would be

$$S' = S\,\frac{R'^2}{r'^2} = 1 \times \frac{(6360.44)^2}{(43000)^2} = .02198,$$

and since $\frac{1}{.02198} = 45.7$, this number represents Jupiter's surface relatively to the earth when reduced to Jupiter's density.

Also, $$S' = \frac{S\,R'^2}{R^2} = \frac{1 \times (6360)^2}{(3959)^2} = 2.581$$

times the earth's present surface.

In this case the surface of Jupiter, in relation to that of the earth, would be 45.7. as before, and the relative duration of his planetary periods would be 6.761, as before.* But basing a calculation on Jupiter's actual volume, as ordinarily stated, we find the relative length of his planetary periods to be 2.62. Some idea of the relative energy of meteorological forces on this planet may be had by recalling the fact that the velocity of the trades and anti-trades is determined by the velocity of a point on the planet's equator. In Jupiter, we have a planet rotating 2.4 times as rapidly as the earth, with a radius 11 times as great. Hence, a point on his equator moves more than 26 times as rapidly as a point on the terrestrial equator; and other things being the same, the Jovian trades and anti-trades should move with a terrific velocity. Their effects, moreover, would be increased six-fold by the superior density of Jupiter's atmosphere. But other things are not the same, since the solar heat at the distance of

*Jupiter's actual surface in relation to the earth's actual surface is 117.9. The earth's surface, if having the density of Jupiter, would be, in relation to the present surface, 2.581; and hence Jupiter's actual surface in relation to the earth's, if having Jupiter's density, would be $\frac{117.9}{2.581} = 45.7$,— the same ratio as when Jupiter is supposed reduced to the earth's density. It may be readily shown that this is as it should be, for,

Let S and s represent the surfaces of the earth and Jupiter,

S′ and s' their surfaces respectively, when each is reduced to the other's density,

R and r their actual radii, and R′ and r' their radii respectively, when reduced each to the other's density;

Then, $s' = S.\frac{r'^2}{R^2} = \frac{r'^2}{R^2}$ when S = 1; and $s = S.\frac{r^2}{R^2} + S.\frac{R'^2}{R^2} = \frac{r^2}{R'^2}$.

Now, if σ and σ' represent Jupiter's two supposed densities, and ρ and ρ' the earth's, and v, v', V and V′ be employed similarly for volumes of Jupiter and the earth, we have

$$\frac{\sigma}{\sigma'} = \frac{v'}{v} = \frac{r'^3}{r^3}; \therefore r'^3 = r^3.\frac{\sigma}{\sigma'}, \text{ and } \frac{\rho}{\rho'} = \frac{V'}{V} = \frac{R'^3}{R^3}; \therefore R'^3 = R^3.\frac{\rho}{\rho'}.$$

But $\sigma' = \rho = 1$, and $\rho' = \sigma$; $\therefore r'^2 = r^2\,\rho'^{\frac{2}{3}}$, and $R'^2 = \frac{R^2}{\rho'^{\frac{2}{3}}}$.

Hence, by substituting $s' = \frac{r^2\rho'^{\frac{2}{3}}}{R^2}$, and $s = \frac{r^2\rho'^{\frac{2}{3}}}{R^2}$; $\therefore s' = s$.

Jupiter is only $\frac{1}{27}$ the intensity experienced at the earth — taking no account of the warming influence of the superior density of the atmosphere. As solar heat is the cause of the atmospheric circulation, it appears that the velocity of the Jovian trades must be about the same as that of the terrestrial trades, if the Jovian atmosphere is of the same depth. But the solar thermal disturbance of equilibrium being less, the velocity of the movement due to this is less: the velocity to and from the equator is less rapid, and for this reason, combined with the superior rotary velocity of the planet, the resultant movement across the meridians approaches much more nearly a right angle. The Jovian atmosphere, also, as will presently be seen, is probably much deeper, as it certainly is much denser, than that of the earth; and the heat radiated from the planet more than compensates, probably, for deficiency of solar heat. Hence it is fair to infer, finally, that the circulation of the atmosphere is much more active and powerful upon Jupiter than upon the earth. Professor Hough reports drifting movements of white spots on his disc at the rate of 260 miles an hour, and these also in the direction of the planet's rotation. This state of things offers an explanation of the belted condition of Jupiter's equatorial region.*

2. *Jupiter's Retarded Development.*—The data just presented concerning Jupiter's physical condition bring to view a stage of world-life very remote from that on the earth. The superior volume of Jupiter, if constituted like the earth, should give it a density many times greater than the earth, instead of one-fourth as great. Some remarkable planetary cause produces this great difference. The visible surface of the planet is constituted of moving and

* On the remarkable bright "red spot" visible on Jupiter's disc in 1879–80–1–2, see *Nature*, xxvi, 613, Oct. 19, 1882, for a notice of studies by Professor G. W. Hough, at Dearborn Observatory, Chicago, from his *Annual Report*.

changing vapors, which, by the rapid axial rotation, are drawn into parallel belts, especially in the equatorial region. These appear to exclude from view, perpetually, the real body of the planet. Moreover, the presumed relations of the atmosphere to the mass and surface gravity of the planet point out exceptional conditions. If the atmosphere on Jupiter sustains the same relation to the planetary mass as the terrestrial atmosphere to the earth's mass, it must be accumulated to nearly three times the terrestrial amount over each square mile of surface. Since Jupiter's mass is 309 times the earth's, while his surface is only 118 times as great, this atmosphere would therefore be accumulated over each unit of surface in 2.62 times as great quantity as on the earth, and would therefore, for this reason, be 2.62 times as dense as the earth's atmosphere. But as Jupiter's gravity is $2\frac{1}{4}$ times as great as the earth's, the actual density would be over 6 times as great as the earth's.* The Jovian atmosphere reduced to uniform surface density would reach an altitude .4123 that of the earth's homogeneous atmosphere; that is, only 2.075 miles.† All corresponding densities in Jupiter's

*In the formula previously employed (p. 411) $\frac{m}{M} = 309$; $\frac{S}{s} = \frac{1}{117.9}$; $\frac{g'}{g} = 2.254$ (*Annuaire*, 1881). Hence $p = P \times 6.357$; and if P = 30 inches, $p = 190.71$ inches of mercury. This pressure is equivalent to that which would exist in the bottom of a shaft on the earth 91.8 miles deep, and would raise the temperature of boiling water to 302° Fahr., which is somewhat less than the *experimental* result for saturated steam under the same pressure on our planet.

†If u = the volume of the atmosphere of a planet,
s = the surface of the planet,
m = mass of atmosphere. (If this is taken relative to mass of earth's atmosphere, then m = mass of planet relative to earth's mass.)
σ = density of atmosphere at surface of the planet,

then $h' = \frac{u}{s}$ approximately.

But $u = \frac{m}{\sigma}$; $\therefore h' = \frac{m}{s\,\sigma}$.

For Jupiter, the relative values of these constants are $m = 309$; $s = 117.9$; $\sigma = 6.357$ ($= p$ in last note); hence $h' = .4123\ h$.

To get h, the height of the earth's homogeneous atmosphere, we have $h = \frac{U}{S}$.

atmosphere would be correspondingly lower than in the earth's. That is, half the surface density would be reached at $1\frac{1}{2}$ miles, while on the earth it is reached at $3\frac{1}{2}$ miles. The inference is, as Professor Proctor has shown, that the floating clouds of Jupiter's atmosphere must rest in comparative proximity to his surface, instead of being elevated to atmospheric heights proportional to Jupiter's volume. But astronomical observers inform us of phenomena which make it necessary to admit considerable depth to the cloud-layer. The special black lines in the spectrum indicate, in all the exterior planets, deep and dense atmospheres. Should we admit a depth of thirty miles, this would imply such a volume of atmosphere as would condense the surface layers to fifty times the density of platinum. We are compelled to assume, therefore, that a very peculiar planetary condition exists on the surface of Jupiter. Some cause is in action which at the same time greatly reduces the density of the planet and greatly increases the volume of the cloud-bearing envelope.

Now, on the principles of the nebular theory, it is perfectly legitimate to assume that Jupiter is lingering in the high thermal stages of planetary life. I have shown that progress on his surface must be $6\frac{3}{4}$ times as slow as on the earth; so that if Jupiter had emerged as a separate body at the same epoch as the earth, he must lag far behind in development. It is quite supposable that though his planetary existence may have begun long before the earth's he may not, for all that, be so far developed, and

But $U = .003837 \times \frac{4}{3} \pi R^3$, and $S = 4 \pi R^2$; therefore $h = .00127\ R = 5.033$ miles. This is given also by the height of the column of mercury in the barometer.

To get .003837, relative volume of earth's atmosphere, we have

Mass of atmosphere $= \frac{1}{1200000} = .000000833$ (Herschel).

Density of air $= \frac{1}{813.67}$ (Regnault).

Density of air compared with earth's density $= \frac{1}{813.67} \times \frac{1}{5.66}$.

Hence $U = \frac{4}{3} \pi R^3 \times 5.66 \times 813.67 \times .000000833 = \frac{4}{3} \pi R^3 \times .003837$.

may even have but recently reached the stage of incipient incrustation and cloud formation. The implied temperature would retain his density at a comparatively low figure, and would, besides, evolve a volume of cloud-supporting gases which would greatly exaggerate the apparent diameter of the planet. I have shown that if possessed of the density of the earth, his diameter would be 53,000 miles instead of 85,000, so that to present his present apparent volume, there must be an atmosphere capable of bearing clouds 16,000 miles above his solid surface. As no such atmospheric thickness is admissible, the planetary body must actually possess much less density than the earth; and this condition can be most naturally referred to heat as its cause.

The luminosity of Jupiter seems to confirm this conclusion. Experiments made by Zöllner* on the light emissive powers of the moon and the planets exterior to the earth, after making all allowances for difference of distances and diameters of the bodies, supply us with data from which the following table may be calculated:

COMPARATIVE LIGHT-EMISSIVE PROPERTIES.

Moon	1.000	Saturn	2.869
Mars	1.539	Uranus	3.687
Jupiter	3.598	Neptune	2.794

Now, it is universally admitted that the lunar surface presents the condition of cooled and solid rocks, somewhat analogous to the surface of the earth. It is reasonable to assume that the moon's reflective powers are about as great as a surface of the lunar or terrestrial character can attain. Of what, then, must the surfaces of Jupiter and the remoter planets be composed to possess reflecting powers from $2\frac{1}{2}$ to $3\frac{1}{2}$ times as great as the moon? It is safe to deny that any such reflecting powers are possessed

* Zöllner: *Grundzüge einer allgemeinen Photometrie des Himmels.* Berlin, 1861.

by planetary masses. The only alternative is the admission that Jupiter and his giant companions possess still some amount of inherent luminosity, or are wrapped in envelopes possessing higher reflecting powers than solid planetary materials.

The rapid rotation of Jupiter is evidence that tidal action, presently to be mentioned, has not gone far in destroying its rotary velocity. The younger and smaller planets have suffered much in this respect. Rapid rotation, according to our theory, is a characteristic of early periods of planetary history; and we here discover confirmatory evidence of Jupiter's primitive stage of evolution.

The most careful scientific examination of the physical condition of Jupiter's surface seems, therefore, to reveal the actual existence of a state of affairs supposed to have been long passed in the evolution of our own planet. The stormy stage of Jupiter is a fact before our eyes, while the stormy stage of the earth has been reproduced to thought only by a process of retrograde deduction. It would be vain to attempt to depict the precise nature of the events taking place on this gigantic mass, working out its planetary development in the solitudes of boundless space. If the planetary body shines with all the brilliancy of a molten globe, his light is screened by a dense veil of aqueous vapors. Were Jupiter's mass no greater than the earth's, we might not, perhaps, expect the condensation of aqueous vapor at so early a stage of cooling; but as I have shown, on a planet of such mass, the temperature of vapor formation would be as high as 302° Fahr. Whatever the condition of the planetary body, it is incandescent, and the gathered clouds are thick and dense enough to precipitate their rains. Into what a furnace of consuming heat are the rains falling! Now, while we write, that stupendous and violent circulation of descending waters and ascending vapors which we have conceived as a ter-

restrial scene long past, is in progress on an actual planet. The lightnings are darting and the detonations of the responsive thunders are resounding, and the noise is magnified by the six-fold density of the medium which transmits it. To the naked eye, how mildly does Jupiter beam upon our earth! What profound stillness reigns in the regions of the sky where his majesty rides! Can we gaze upon that silent, placid orb and imagine that the elements there are rending each other in very madness, and the roar of their clashing would stun the most insensible ears? We have good grounds, however, to picture the home-life of Jupiter in the most startling colors.

Not long since, cosmologically speaking, Jupiter was shining with cloudless self-luminosity. He was still a real sun revolving about our great common centre. There are regions in space from which our sun shines like a fixed star. From Sirius he appears as a star of a low order of magnitude. When the astronomers in those regions scanned our star some millions of years ago, they catalogued it as a double star. It had an attendant which revolved about the principal star in periods a little less than twelve of our years. So Alvan Clark, from our terrestrial standpoint, has detected a self-luminous planet revolving about Sirius. This is the Jupiter of the Sirian system. But its period is fifty years, or about four times that of our Jupiter. Thus we may contemplate Jupiter as marking distinctly one of the necessary phases of a cooling cosmical globe.

3. *Tidal Action on Jupiter.*—Jupiter's evolution must be perceptibly influenced by the tidal action of his satellites. The distances and masses of these satellites in relation to their primary are given in astronomical tables, and from these I have calculated their distances in relation to our moon's distance from the earth, and their masses in relation to our moon, and also the vertical fluc-

tuations they are capable of producing on the water-covered planet.* The following table gives the results:

Satellites.	Masses (Moon's = 1)	Densities (Moon's = .607)	Distances (Moon's = 1)	Tidal Effects (Inches)
I.....	.424	.2009	1.084	88.21
II	.5835	.3890	1.725	33.07
III	2.222	.3377	2.754	28.13
IV	1.067	.2618	4.842	2.49

The calculation was necessarily based on a planetary diameter as large as given in the tables. The result illustrates the predominant importance of distance in tidal actions, since the second satellite, with more than a third more mass than the first, but with two-thirds greater distance, has only three-eighths as great tidal efficiency. The first satellite, also, with only two-fifths the mass of our moon, and 20,000 miles more distant from the centre of its primary, exerts one and a half times the amount of tidal efficiency. This results from the fact that Jupiter's diameter is more than eleven times that of the earth.

It will be recalled that considerable importance has been attached to lunar action in the history of the earth, even since the attainment of an advanced stage of incrustation. A Jovian satellite possessing fifty per cent greater efficiency can not be overlooked as a working factor in Jovian evolution. The joint action of the first and second satellites is more than double our moon's influence; and the joint action of the three nearest satellites amounts to two and a half times our moon's influence on the earth, or a total fluctuation of 12½ feet. Concurrences, or approximate concurrences, of tidal action very frequently happen.

But the most important consideration in connection with the passing history of the planet, is the aëriform

* Employing the same formula as previously, we have, for the first satellite, $\frac{D^2}{d^3} = \frac{(240000)^3}{(260000)^3} = \frac{(12)^3}{(13)^3}$; $\frac{\mu}{m'} = \frac{.000016877 \times 309}{.0123}$; $\frac{r}{R} = 11.061$; $\frac{g}{g'} = \frac{1}{2.425}$; whence $t = 88.21$ inches. The calculation is similar for the other satellites.

state of the tide-moved ocean which conceals the body of Jupiter from our view. This yields with many times the facility of water, and the linear extent of the tidal deformation is correspondingly greater. If we could assume the aëriform envelope of Jupiter to be of the nature of pure air, which is 813.67 times as light as water, we should have, by dividing this number by 2.425, the relative intensity of gravity on Jupiter's surface, the actual density of the fluid subjected to tidal fluctuation. This density would be 335 times less than that of water, and would be moved, very approximately, to 335 times the extent. In other words, the first satellite must produce a fluctuation of 2462 feet; the second, one of 925 feet; the third, one of 784 feet, and the fourth, one of 70 feet. The concurrent action of the first two must produce a difference of 6774 feet in the two diameters of the planet; and the concurrent action of the first three would cause a difference of 8342 feet, or more than a mile and a half, in the flood-tide and ebb-tide diameters of the planet, and thus contribute something to the marked ellipticity which it reveals.

Solar tidal action on Jupiter is so diminished as to produce a total fluctuation of only one and one-fifth inches if the planet were water-covered. Still, this is equivalent to a fluctuation of 33½ feet in the aëriform envelope; and this amount of disturbance must be added to that caused by the satellites.

The retardative influence of the Jovian tides seems to be now in the period of its highest efficiency. Jupiter, like any other planet in a state of rapid rotation, suffers the influence of a correspondingly large lagging angle in the tide; and this augments the efficiency of the retardative component of the tidal force. But, while Jupiter or any other planet exposes an aëriform envelope to be acted on, the free mobility of its parts presents, so far as

its movements are concerned, a compensation for rotational velocity. When, however, any large part of the planet exists as a liquid or as a viscous solid, a high rate of rotation must develop a large angle of lagging and a large retardative factor. A planet, therefore, like Jupiter, as we understand it, cloud-covered above and semi-liquid within, though still for the time being in an early formative stage, exists at the same time, under those conditions of high rotation and semi-liquidity which tend to degrade most rapidly its rotational velocity. A relatively brief epoch, however, in the history of a planet having 309 times the mass of the earth, is numerically long in the history of the earth. Hence it is, as before suggested in reference to the dissipation of a planet's thermal energy, that a planet older than the earth in years is so much younger in development.

So far, moreover, as rate of evolution depends on tidal retardation, a planet of large mass is more slowly influenced than one of smaller mass, by a given tidal efficiency. The horizontal component of the tidal force has indeed the advantage of acting at the extremity of a longer radius, but this advantage is only proportional to the first power of the radius. The resistance to it, for a given velocity, is proportional to the moment of inertia, or about the fifth power of the radius.* These relations tend very greatly

* The moment of inertia of a sphere is measured by the mass into the radius of gyration, or, in common language, $= M k^2$. Among spheres of the same density, and having *uniform internal density*, moment of inertia $= \frac{4}{8} \pi r^3 \times \frac{2}{5} r^2 = 1.6758\, r^5$. That is, resistances to action of horizontal component of attraction on tidal protuberance are measured by 1.6758 times the fifth power of the radius; but they are supposed applied at the extremity of the radius of gyration, which is equal to $.6325r$. A unit of force applied here is equivalent to .5811 applied at the extremity of the radius. Hence the moment of inertia of the sphere, supposed applied at the extremity of the radius, where the retardative force is applied (very approximately), becomes $1.6758r^5 \times .5811 = .9736r^5$. That is, the effective resistance of the moment of inertia is as the fifth power of the radius.

to a relative prolongation of evolution stages in the larger planets.

4. *Tidal Effects and Densities on Jupiter's Satellites.*— I have heretofore pointed out the remarkable tidal influence exerted by the earth on the moon, and it is proper to consider what part has been performed by the tidal influence of Jupiter in the evolution of his satellites. Two circumstances point at once to the certainty that the tidal action exerted by Jupiter must be enormous. His mass is 309 times that of the earth, and 25,122 times that of our moon, and hence, other things being the same, the lunar tide on the earth must be multiplied by this number to show the magnitude of the Jovian tide on one of his satellites. *Secondly*, the satellites all possess a lower intensity of gravity than the earth, and for this reason, with a given diameter they present less resistance to the tide-raising efforts of the planet.

If we consider the case of the first satellite, and suppose, for the sake of comparison, that an ocean covers its surface, it will be evident *first*, that so far as mass of the tide-mover enters into the calculation, it is 25,122 times that of the tide-mover in the case of lunar tides on the earth. *Secondly*, so far as concerns the effect of distance, it will be as the cube of 12 to the cube of 13, which is .7865. *Thirdly*, assuming, as heretofore, that the linear altitude of the tide is proportional to the radius of the tide-bearer, the value of this factor will be as the radius of the satellite to the radius of the earth — that is, as 1176 to 3963 which is .2967. *Fourthly*, the relative intensities of gravity on the satellite and on the earth will constitute another factor, and the height of the tide will be inversely proportional to the two intensities. These a little calculation shows to be as .05922 to unity, the reciprocal of which is 16.89. The product of these four factors shows that the Jovian tide on the first satellite is 99,000

times as great as the lunar tide on the earth. If we desire to express this in some comprehensible measure, we may assume, as heretofore, that the tidal linear fluctuation of the lunar tide is 58 inches; and from this it will result that the tidal effect of Jupiter on his first satellite is equivalent to an oceanic fluctuation of more than 90 miles.* This amazing result indicates a degree of prolateness in this satellite which possibly might be detected by the best measurements; though 90 miles, at the distance of Jupiter, subtends an angle of only one twenty-fifth of a second. That is to say, if the satellite, while making a transit across the planet's disc, has an angular diameter of 1″.02, it should have at its elongations a horizontal diameter of 1″.06.

To the tidal effect must be added the tidal effects of any other satellites when in conjunction with the first one. A little calculation shows that the tidal effect of the second on the first, when in conjunction, is over fifty-three feet of water.†

With this disclosure of the tidal distortion of the Jovian satellites, we can appreciate the certainty of their rapid approach to a state of synchronistic rotation. If this state was not attained before the disappearance of the water belonging to one of them, the tidal oscillations must have acted with most destructive energy upon the

*We may adapt the formula heretofore used, and abbreviate the operation as follows: In the expression

$$t = \mathrm{T} \cdot \frac{\mathrm{D}^3}{d^3} \cdot \frac{r^3}{\mathrm{R}^3} \cdot \frac{\mathrm{M}}{m} \cdot \frac{\mu}{m},$$

d = distance of first satellite from Jupiter,
r = radius of the same, and m = its mass,
μ = the mass of Jupiter.

Hence, $t = 58 \times \frac{(12)^3}{(13)^6} \times \frac{(1176)^3}{(3963)^3} \times \frac{1}{.0123} \times \frac{1}{.000016877} = 5{,}743{,}000$ inches $= 90.64$ miles.

†Applying still the general formula,

$$t = 58 \times \frac{(280)^3}{(154)^3} \times \frac{(1176)^3}{(3963)^3} \times \frac{1}{.000016877} \times \frac{.000023227}{.0123} = 641.8 \text{ in.} = 53.48 \text{ feet.}$$

solid crust. The tidal movements of the crust itself developed constant fissures through which the molten interior escaped in enormous ejections, and the planetary waters poured within, developing explosive energy sufficient to hurl fragments beyond the sphere of the satellite's attraction. If the volcanic action continued after the retirement of the water, as I have assumed in the case of our moon, a process of crater formation must have taken place similar to that occurring on the moon, but as much more violent as the tidal efficiency was greater on the Jovian satellite. It is to be presumed, therefore, that it presents a disc more fearfully scarred than that of our moon. The enormous irregularities of the surface present, in the course of a rotation, various aspects toward the sun. In some situations the exposures are such as to reflect much more light than in others; and hence the brilliancy of the satellite varies, as has been observed. But, in this view, the same aspects should reappear with each return of the same exposure. If these reappearances should be found correlated only with the orbital movements, the fact would indicate that the axial rotation moves synchronously with the orbital revolution. If it should appear that the recurrences do not correspond with orbital positions, it must be inferred that synchronism does not exist; and then the period of the recurrences might afford a clew to the satellite's period of rotation. But on theory it may be conjectured that the recurrences stand only in relation to orbital movements.*

A study of the densities of these satellites affords some very suggestive results. The densities have been already included in a table of the satellites on page 435. Taking the earth's density as unity, they range from one-fifth to two-fifths. The density of our moon is three-fifths. Sat-

*Father Secchi, nevertheless, states that he has observed a rotation of some of Jupiter's satellites (*Le Soleil*, ii, 405).

ellite IV, which has about the mass of the moon, has less than half its density. Satellite III, with two and a quarter times the mass of the moon, has little more than half its density. Now, as these satellites cannot, with any probability, be regarded as enshrouded in warm vapors, or even in a high thermal state, they are in a fair condition to compare with our moon; and when we find them possessing a greatly lower density than our moon, we are constrained to believe them composed of lighter materials.

Again, Jupiter and his satellites might be conceived as formed of materials of nearly the same density. But as Jupiter possesses 59,250 times the mass of the first satellite, and 11,310 times the mass of the largest satellite, the vast condensation existing in his interior should give him a much greater density than any of his satellites. But, on the contrary, his density is only one-fourth that of the earth. This remarkable fact affords further indication of Jupiter's high thermal state.

If, as we argue, the materials of Jupiter's satellites embrace a larger proportion than the earth of aqueous and gaseous compounds, then the solid and cooled body of one of these satellites would be less capable of effecting a complete absorption of the fluids, as has taken place on our moon. It is, indeed, quite supposable that the fluids should exist in such proportion as to suffice for saturating the pores of the cooled planet, and supplying a surplus to cover its surface. We must bear in mind, then, the possibility that these and other and remoter satellites of our system remain actually water-covered. A vapor-laden atmosphere might possibly restrain within it sufficient solar heat to keep such a watery film, or partial film, in a state of liquidity; but, on the contrary, it is almost certain that the thin atmosphere of these light bodies admits of radiation so free that any surface water is held permanently in a solid state. The possibility of fields of

ice ocean-wide renders it possible that the sun's light should be flashed to us in certain situations of the satellite, giving it a temporary excess of brilliancy. Wide areas, with only the reflecting power of crushed ice or Alpine névé, might, by contrast with the darker upland areas, as is aptly illustrated by the snow-covered polar regions of Mars, produce that variation in reflecting power which, otherwise, I have attributed to mere topographical configuration.

§ 6. THE ULTRA-JOVIAN PLANETS.

Much that has been said of Jupiter may be applied with even increased propriety to all the planets exterior to him. The ringed planet with a diameter more than nine-elevenths the diameter of Jupiter, has less than one-third of his mass, and possesses, consequently, only half its density, or .129 that of the earth. This is only three-fourths the density of water, while Jupiter possesses one and three-eighths the density of water. Gravity at Saturn's surface is, therefore, 1.14 that on the earth. Moreover, the surface of Saturn is veiled in clouds like that of Jupiter, and analogous belts, though fainter, are generally seen drawn across his disc. His relative luminosity is but a little less than Jupiter's. The condition of Saturn is, therefore, more extraordinary than that of Jupiter. If we found reason for supposing the latter to subsist still in a primitive and highly heated stage, the conclusion seems, at first thought, even better suited to the case of Saturn. It must be admitted that in the case of both these planets thermal intensity would suffice to produce the low density observed, only on the supposition that it approaches somewhat that of the sun, whose density is the same as Jupiter's, and twice that of Saturn. But a heat approaching that of the sun is entirely inadmis-

sible, since this would dissipate the aqueous vapors which envelop these planets, and would impart to their light spectroscopic properties truly solar. There is no probable way of accounting for the low density of Saturn but to admit that it is composed, in larger proportion than the earth, of substances possessing a low specific gravity. This conviction carries our thoughts back to the primitive nebular condition of our system, and recalls a conclusion of which we have heretofore been frequently reminded, that the denser matters would gravitate toward the centre of the nebula, leaving the lighter to enter into the formation of the earlier planetary rings. Then it is supposable, also, that Saturn still lingers in a high thermal stage, and that his cloudy envelope, like that of Jupiter, depends on the action of internal heat, and argues the stage of the cosmic rainstorm on the planet's surface. All the evidences of primitive thermal conditions which have been pointed out in Jupiter and his satellites are repeated in the system of Saturn, *except that Saturn's double age introduces a changed relation.*

Of the planets Uranus and Neptune, our information is comparatively imperfect. They are, however, well known to be of nearly equal volume and density, having diameters less than half that of Saturn, and densities approximating that of Jupiter. They are thus but little denser than water.* The inherent luminosity of Uranus is even greater than Jupiter's, and that of Neptune is equal to Saturn's. It is the opinion of Proctor that the reasons for assigning a high thermal condition to Jupiter constrain us to reach a similar conclusion in reference to these planets.

This conclusion, however, is not the only one to be suggested. The theory of partial incandescence in Jupiter is

*The *Annuaire du Bureau des Longitudes* for 1881, however, gives the density of Neptune as .410 compared with the earth, while that of Uranus is .234, and that of Jupiter .242.

admissible. But Saturn is both an older planet and a smaller one. It should be further advanced in its evolution. But its density is even less than that of Jupiter. We cannot pursue the line of reasoning employed in Jupiter's case, and infer still higher incandescence than we may admit in Jupiter. The embarrassment is repeated and augmented as we recede from Saturn to Uranus, and from Uranus to Neptune. We seem constrained to seek some other explanation more in harmony with the doctrine of successiveness in planetary origins and the necessity of some relation between age, amount of internal heat, and rate of cooling.

The great facts in the case of the three outer planets are enormous bulk, low density, exceptional brilliancy and, as is probable, great relative age. Any hypothesis concerning their physical condition must harmonize these four facts. Now, our theory requires a gradation in densities corresponding with approximation toward the centre of the system. The superior age of the remoter planets requires them to be more advanced in their evolution, and their superior mass requires them to be less advanced. Their actual condition is the resultant of these two requirements, and it may not be possible to ascertain whether it is a stage of world-life more or less advanced than that of the earth.

Apparently, however, strong reasons exist for regarding the ultra-Jovian planets as far more advanced than the earth. An attempt to calculate the relative duration of their cosmic periods brings out unexpected results. Any precise calculation is impossible, in consequence of their relatively low density and the impossibility of ascertaining their true volumes, arising from the vapors which conceal the true planetary bodies. But, assuming the dimensions of these planets to be such as are usually given in the tables, and making the calculations according to the

principles heretofore explained, we find that the cosmic periods of Saturn exceed those of the earth by only one-seventh, while Uranus and Neptune have cosmic periods of only three-quarters the length of the terrestrial periods. Those planets held primitively many times the quantity of heat possessed by the primitive earth, but their relative surfaces gave them power of radiation in equal or greater ratio. It has been generally conceived that cosmic periods were longer on all the remoter planets, but, after allowing for all chances of error in calculation, it appears certain that the ultra-Jovian planets advanced at about as rapid a rate as the earth. Their vastly superior age seems, then, to afford very strong evidence that they have not only passed the Jovian stage, but even the terrestrial. The vapors, therefore, which envelop them cannot arise from any heat comparable with that supposed to be perpetuated in the planet Jupiter.

Now, will it be allowable to entertain these conceptions of Saturn, Uranus and Neptune, and hold at the same time to the partial incandescence of Jupiter? Can we maintain heat as the cause of Jupiter's low density, and a cooled aqueous condition as the cause of the low density of the remoter planets? This, I admit, is a question which ought to be considered open. Perhaps Jupiter, also, is a cooled aqueous globe, instead of a globe in its high thermal and stormy stage. Assuredly, we must concede to Jupiter a much larger proportion of water and gases than the earth possesses; but must we affiliate the planet in constitution and stage of development with Saturn more than with the earth and a certain stage in its life history? In passing from Jupiter to Saturn the distance is more than doubled which separates Jupiter from us. If the interval which separates Jupiter from us justifies all the assumed contrast in conditions which has been indicated, the greater distance between Jupiter and Saturn

justifies an equal contrast, and all the more when we consider that Jupiter's cosmic periods are twice the length of Saturn's. But the comparison is not alone between Jupiter and Saturn, but between Jupiter and the *group* of remoter planets. What does the mean distance of this group from Jupiter suggest and demand in reference to comparative conditions? What does the extreme distance demand? Uranus is four times as remote from the earth as Jupiter is, and Neptune is more than seven times as remote. There is space for enormous contrasts of conditions, even with cosmic periods as long as Jupiter's.

If Saturn is composed of materials less dense than those which make up the bulk of our earth, what are those materials likely to be except water, atmospheric air, perhaps with the constituents mixed in different proportions, gaseous hydrocarbons and carbonic anhydride? In addition, there must be smaller proportions of the various solid constituents of the earth. If Saturn were composed wholly of water, his density would be greater than it is in consequence of central condensation. If he possessed, in addition, a superior allotment of gaseous constituents, they would clothe the watery globe with an atmosphere. In the centre of the globe of water would be accumulated all the solid constituents. Incrustation would be the freezing of an icy film upon the watery surface; but it would begin late and only at a much lower temperature than rocky incrustation. The prolonged liquidity of the planet would prolong the process of convective cooling, and thus accelerate planetary refrigeration beyond the rate already indicated. So old a planet cooling by convection should have passed the thermal stage. Enormous internal condensation might deprive some of the watery mass of the properties of a liquid, and thus arrest partially the convective process, while cooling would proceed by radiation from the surface,

The incidents in the formation of an icy crust would present a complete analogy with the history of terrestrial incrustation. A watery planet would never absorb completely its atmosphere, especially if we assume a greater relative volume on such a planet. At all stages of cooling, therefore, a voluminous atmosphere would be present, and at all temperatures the vapor of water would rise and load the atmosphere with clouds. The cloudy envelope would increase the apparent diameter of the planet, and lead to an underestimate of its density. Even with the central condensation due to the mass of Saturn, the actual mean density might not be greater than what we actually observe. At the same time the reflecting power of the cloudy envelope might impart to the planet that extraordinary degree of luminosity which Zöllner has determined. The relative brilliancy of Saturn ought, in this view, to be much greater than that of the rocky disc of the moon. If these considerations are applicable to Saturn, they are quite as applicable to Uranus and Neptune. Uranus is said to present some spectroscopic indications of a peculiar character. In reference to this, we can understand that, according to our theory, the two outer planets should contain progressively more of the gaseous constituents, but this is all which can at present be suggested.

Should the views here set forth be true respecting the excess of watery and aëriform constituents in these planets, then tidal action upon their surfaces could never have produced, since their fire-mist stage, the retardative effects experienced by planets which pass long periods in a state of molten viscosity. As long, also, as their waters maintained an unfrozen state, the retardative action of their tides would be small compared with terrestrial oceanic tides, since no continental barriers to tidal motion would be interposed, and the only retardation would arise from

the low viscosity of water. When incrustation (ice formation) began, even this action of watery tides would be greatly diminished, and would finally cease. Much, therefore, of the primitive rotational velocity of such planets must be retained to the present epoch. This inference agrees with our best observations.

In view of these considerations, it does not seem a violent supposition to assume an aqueous and cold condition for Neptune, and a semi-aqueous and heated condition for Jupiter. Then, further, the similarity of the indications from Saturn, Uranus and Neptune is significant. If they were still in planetary progress they would not exhibit the same stage of evolution. How could identity of condition exist unless that condition be a planetary finality? No planet can pass a state of total refrigeration. Perhaps Neptune attained this and remained changeless. Uranus later attained it and remained changeless. Saturn, even, has attained it, and the three oldest planets accordingly have run their courses equally, and have alike attained the death which levels all distinctions.

Under any theory the four remoter planets present existing conditions widely different from those of our planet. In the view here suggested, the three remoter planets evince conditions of constitution so diverse from those of the earth that the terrestrial state can never have been assumed, though the terrestrial stage may long since have been passed. These planets roll on through the still and changeless winter of their planetary life — globes of crystal wrapped in stagnant fogs which the sun's feeble ray is unable to stir to the movements which characterize a living world.

TABLE OF SOME PLANETOGENIC CONSTANTS.

	Radius, miles, and Earth=1.	Surface. Earth = 1.	Volume. Earth = 1.	Mass. Earth=1	Density. Earth = 1.	Solar Intensity. Earth=1 at mean.	Cosmic Periods. Earth=1	Solar Tidal Efficiency. Earth=1.	Linear fluctuation of Solar-tide. Earth=1.	Atmospheric Pressure. Earth=1.	Height of Barometer. Earth=30.	Water boils. Earth=212° Fahr.	Height of Homogeneous Atmosphere.
									feet.		inches.	Fahr.	miles.
Mercury	1,529 .3858	.1489	0574	.065	1.132	Perihel. 10.58 Aphel. 4.59	.4366	17.24	44.68	.1882	5.646	130°.8	11.67
Venus	3,830 .9475	.9061	.855	.885	1.03	Perihel. 1.94 Aphel. 1.91	.9767	2.643	7.37	95.95	29.78	211°.64	5.123
Earth	3,963 1.000	1.000	1.000	1.000	1.00	Perihel. 1.034 Aphel. .967	1.000	1.000 Lunar 2.228	26.03 in. Lunar 58 in.	1.000	30.000	212°.00	5.033
Moon	1,080 .2725	.074	.020	.0123	.607		.1679	Geal 134	Geal 647.67 ft	.0279	.836	37°.5	29.98
Mars	2,181 .5508	.2828	.167	.108	.6481	Perihel. .524 Aphel. .360	.3917	.4306	21.31 in.	.138	4.14	115°.5	13.96
Jupiter	42,421 11.061	117.9	1279.4	308.99	.242	Perihel. .041 Aphel. .034	6.761 to 2.62	.0071 1st Sat. 1.521	1.21 in. 1st Sat. 88.21 in.	6.357	190.71	302°.00	2.075
Saturn	35,068 8.849	78.300	692.89	89.69	.1294	Perihel. .0123 Aphel. .0099	1.145			1.307	39.21	225°.4	4.411
Uranus	16,623 4.195	17.612	73.85	12.65	.1713	Perihel. .0027 Aphel. .0025	.7187			.515	15.45	179°.5	7.029
Neptune	18,638 4.703	22.119	104.02	16.77	.1612	Perihel. .0011 Aphel. .0011	.7582			.573	17.19	184°.9	6.650
Sun	426,450 105.421	11,519	1,246,040	316,000	.2536		27.29			1.007	30.21	212°.3	134.6

Remarks on the Table of Planetogenic Constants.

1. The "cosmic periods" are identical with relative intensities of gravity on the surfaces of the planets; since $g' = g \cdot \frac{m}{M} \cdot \frac{R^2}{r^2}$, where g', m and r are gravity, mass and radius of the planet, and g, M and R are gravity, mass and radius of the earth. But this expression is equivalent to $g \cdot \frac{m}{M} \cdot \frac{S}{s}$, where s and S are surfaces. But, making the terrestrial values g, M and S equal to unity, we have for relative gravity, $g' = \frac{m}{s}$, which is identical with the expression for relative cosmical periods.

2. The "linear tidal fluctuations" are intended to show what would take place on ocean-covered bodies similar to the earth, and not to imply that such tides have ever actually existed, in each case, or ever will exist. Still, about this we can neither affirm nor deny positively. They stand, at least, as measures of tidal forces and tidal effects in some form.

3. The values entered in the last four columns cannot be very exact. They rest on the assumption of physical conditions analogous with those of the earth; but this we know is not generally the fact. Besides the differences in the ratios, in different parts of the system, between the fluid and solid constituents, the differences in thermal conditions and states of matter vitiate the results obtained, especially in regard to the remoter planets and the sun. The same is true respecting the column of cosmic periods. Still all these results are suggestive and interesting.

CHAPTER IV.

PLANETARY DECAY,

OR COSMIC CONDITIONS MORE ADVANCED THAN THE TERRESTRIAL STAGE.

Physico-mechanical laws are, as it were, the telescopes of our spiritual eyes which can penetrate into the deepest night of time, past and to come.—HELMHOLTZ.

Everything cosmical must be gradually decaying.—P. G. TAIT.

§ 1. EXTREMELY ERODED CONDITIONS.

THE erosion of the terrestrial surface has been in progress ever since the emergence of the oldest land. The chief erosive agents are waters, frosts and winds. The action of these agents is everywhere facilitated by changes in the state of cohesive and chemical aggregation of the parts. The forces of cohesion and chemism are influenced by temperature, and this sometimes varies with the rate of escape of heat from the planet's interior. The total amount of erosion which the earth's surface has endured is measured by the total amount of sedimentation which has taken place since land first appeared. The whole mass of the existing sedimentary rocks measures only a part of this denudation, since older sedimentary rocks have been repeatedly reduced to sediments and reëlevated in later ages. Not only have vast volumes of earlier sedimentary formations been worn out and rewrought into later formations, but the entire mass of the primitive fire-formed crust has disappeared — on its lower surface by refusion, but on its upper surface by erosion and chemical dissolution.

During the progress of these erosions, mountain masses have shrunken in dimensions, continental surfaces have been lowered, and oceanic basins have been progressively filled — more especially along the continental borders. There are good geological grounds for believing that extensive land areas have disappeared* — partly by erosion, but sometimes by subsidence — while the progressive emergence of the principal continental masses has been going forward. All geological evidence, however, points toward the conclusion that no general interchange of oceanic and continental regions has ever taken place.

The first effects of terrestrial erosions lie exposed to our observation on a vast scale. Some of these are results whose earlier history reaches back into the middle or beginning of Mesozoic Time. The old Niagara gorge began, probably as soon as the drainage course was established from the Superior Sea to the Gulf of St. Lawrence. This could have been even in Palæozoic Time. The Ohio, Upper Mississippi, Hudson, Connecticut and many other river valleys began to be excavated at epochs equally remote. The work in all such cases has been in progress to the present time, except so far as interrupted by the conditions of the Glacial Period. In our trans-Mississippi states and territories are records of erosion equally ancient. But the most conspicuous cases probably date from the Mesozoic or Cænozoic Time. The stupendous cañons of the Colorado, Green, Columbia and other western rivers are features Mesozoic or Cænozoic in their origin, but progressively worked out by agencies which, to our day, have never ceased their activity, however their forces are diminished; as the monuments of the genius and power of classic Greece connect themselves by historic continuity with the feebler activities of modern Greeks exerted under the observation of the world. The broad,

* See the author's *Sparks from a Geologist's Hammer*, 122–51.

scarred and desolated plateaus of the West testify to the removal of thousands of cubic miles of the ancient surface. Some of the greatest of these denudations have taken place in later Tertiary time. The records of erosions begun in a later geological period are universally exposed to view. All except the fundamental features of our topography have been carved out by erosive agencies in post-glacial times.

The mode of action of these agents is matter of daily observation. Every turbid summer torrent reveals the transportation of portions of the disintegrated surface of the earth from higher to lower levels. Some of these sediments find their way into the bottoms of lakelets and build up the foundations of marshes and alluvial lands. Some are borne to the larger streams to be deposited on their flooded flats, or carried to the Missouri, the Ohio and the Mississippi. The Mississippi, like the Amazons, the Ganges and the Nile, contributes its annual layer to a thickening delta, and bears the remainder of its sedimentary burden to the sea. In the Gulf of Mexico it builds a bar by the annual accumulation of sediment, which in its growth has encroached sea-ward 338 feet a year. It has already grown far from the ancient Gulfshore, and carried its foundations into the deep waters of the Gulf. Dr. J. E. Hilgard has shown that the deep basin of the Gulf approaches very near to the present bar and present termination of the jetties of Eads.*

By such erosions and transportations the continents are continually lowered and the sea basins are repleted with materials taken from the land. If elevatory forces were as efficient as formerly, the relative levels of the land and

*J. E. Hilgard: *The Basin of the Gulf of Mexico*, "Science" ii, 138-40, March 26, 1881, with a chart. The depth of the water into which the bar has reached will cause hereafter a slower development than in earlier times. The efficiency of the jetties will therefore remain without serious diminution, for a period comparatively prolonged.

sea bottom might be retained; and the relative altitude of the land might be increased. But the elevatory forces must undergo diminution, and the continents must consequently be slowly transferred to the ocean basins. If the amount of surface water remains undiminished, the sea level must slowly rise, and the time must come when the fuller ocean will overflow the shrunken dimensions of the land. When the work of erosive agencies is accomplished, the sea will be universal, as it was before the nuclear wrinkles of the continents first emerged. The earlier and the later conditions of our planet, therefore, present it wrapped in a sheet of water. The continental lifetime is only a temporary emergence of sea bottom accompanying slight movements occasioned by stresses of the earth's interior. Organization seizes the opportunity to rest its foot on the unsteady land; it plays its evanescent role, and the continental swell settles back into the ancient bed from which it lifted its head only for a temporary relief. The ancient ocean still lives; the tidal wave still rolls; the sun rises and sets as before; the moon waxes and wanes: the storms in the atmosphere have died; the sounds of animated nature have perished; life conceals its perpetuated activites in the voiceless depths of the all-subduing sea.

In the annexed diagram A B represents the mean level of the land, E F, the present sea level and C D, the sea bottom. When the continents have been levelled to the present water's surface E P, the ocean will stand at I K, 282 feet deep over all the land. The land above the present ocean level, if thrown into the sea, would raise its bottom to G H, 384 feet. These results rest on Keith Johnson's estimate of about one-fifth of a mile for the mean height of the land. If we take Krümmel's more recent estimates,* we shall have the mean elevation of Europe 300

*Krümmel, *Göttinger Acad.;* G. Leipoldt, *Petermann's Mittheilungen*, Apr., 1875, *Nature*, 15 Apr., 1875, and 3 Feb., 1879, 348-9; *Amer. Jour. Sci.*, III. ix, 482.

m., Asia and Africa, 500m., America, 330m., Australia 250m., giving a mean of 426m., or .2646 mile. This would cause the ocean to stand at I K 373 feet above its

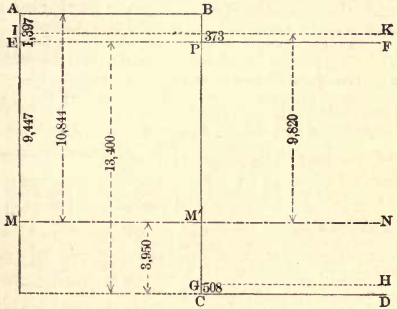

FIG. 59. THE DISAPPEARANCE OF THE LAND.

present level, if all the land were thrown into the sea, and the sea bottom would be raised to G H, 509 feet.

The plane M N which has an amount of land above it equal to the capacity of the ocean's basin below it — that is, the plane which would represent the surface of the land if it were completely levelled down, passes, if we take Keith Johnson's estimate of the mean altitude of the land, 1.42 miles — the distance P M' — below the present level of the sea; or if we take Krümmel's estimate, 1.41 miles. Hence a complete levelling of the land surface would cause the sea to stand 9541 feet above the land, according to Keith Johnson's data, or 9450 feet, according to Krümmel's estimate of the present mean height of the land. The deposit of this amount of land on the ocean's bottom would raise it to M N, 3860 feet, or 3950 feet, according to the data used.*

* Let l = relative surface of land = .167,
w = relative surface of water = .733,
h = mean height of land = E A = $\begin{cases} .2 \text{ mile (Johnson)}, \\ .2646 \text{ mile (Krümmel)}, \end{cases}$

Such are the tendencies of erosive agencies on the terrestrial surface, and such tendencies must exist wherever

d = mean depth of ocean = P C = 2.538 miles,
z = depth of uniform land surface below present sea level = E M,
y = depth of sea over uniform land surface = M I, as appears,
c = C G = depth of covering on sea bottom when land is lowered to E P,
c' = M′C = depth of covering on sea bottom when land is lowered to M N,
x = E I = rise of sea level when land is lowered to E P,
x' = rise of sea level when land is lowered to meet sea level.

I. Suppose land levelled to E P, the present sea level.

Then $x\,(w+l) = lh$, or, since $w+l=1$,

$$x = lh = .267 \times \left\{\begin{matrix}.2\\.2646\end{matrix}\right\} = \left\{\begin{matrix}.0534 \text{ mile}\\.0707 \text{ mile}\end{matrix}\right\} = \left\{\begin{matrix}282 \text{ feet}\\373 \text{ feet}\end{matrix}\right\} \text{ above present sea level.}$$

And $cw = lh$, or $c = \dfrac{lh}{w} = \dfrac{.267 \left\{\begin{matrix}.2\\.2646\end{matrix}\right\}}{.733} = \left\{\begin{matrix}.07285 \text{ mile}\\.09638 \text{ mile}\end{matrix}\right\} = \left\{\begin{matrix}384.6 \text{ feet}\\508.9 \text{ feet}\end{matrix}\right\} = \text{depth}$ of deposit on ocean's floor.

II. Suppose land levelled to meet rising sea level.

Then $l\,(h-x') = wx'$, whence $x' = \dfrac{lh}{w+l} = lh = x$ as above.

III. Suppose the land levelled to uniform land surface M N.

Now, the land surface will be even all over the globe; the present volume of the ocean will be of uniform depth, and we shall have

$$y\,(w+l) = wd, \text{ or, since } w+l=1,$$

$y = wd = .733 \times 2.538$ miles $= 1.8604$ mile = depth of sea all over the earth.

Also to find E M, depth of uniform land surface below the present sea level,

$$l\,(h+z) = w\,(d-z) \text{ and } lz - wz = wd - lh.$$

$$\therefore z = \frac{wd - lh}{l+w} = wd - lh = .733 \times 2.538 - .267 \times \left\{\begin{matrix}.2\\.2646\end{matrix}\right\} = \left\{\begin{matrix}1.8070\\1.7897\end{matrix}\right\} \text{ mile}$$

= depth below present sea level of uniform land surface,

or, $1.8604 - \left\{\begin{matrix}1.8070\\1.9897\end{matrix}\right\} = \left\{\begin{matrix}.0534 \text{ mile}\\.0707 \text{ mile}\end{matrix}\right\} = \left\{\begin{matrix}282 \text{ feet}\\373 \text{ feet}\end{matrix}\right\}$ resulting sea level above present sea level $= x = x'$.

That is, the depth of the overflow is the same as when the land is levelled only to the present sea level. This must obviously be so, since after the levelling of the land meets the rising sea level, all further lowering of the land is simply a change of place of matter within the mass of ocean waters. Hence the line of meeting of the lowering land surface and the rising sea level ought to be as shown above, $\left\{\begin{matrix}282\\373\end{matrix}\right\}$ feet above present sea level. This is the highest which the sea level can be made to attain.

Also, to find M′C, the depth of the deposit over the ocean's floor,

$$c'w = l\,(h+z) \text{ whence } c' = \frac{l(h+z)}{w} =$$

$$\frac{.267 \left\{\begin{matrix}.2\\.2646\end{matrix}\right\} + 1.8066\left\{\begin{matrix}\\\\\end{matrix}\right\}}{.733} = \left\{\begin{matrix}.7311 \text{ mile}\\.7481 \text{ mile}\end{matrix}\right\} = \left\{\begin{matrix}3860 \text{ feet}\\3950 \text{ feet}\end{matrix}\right\} \text{ depth over ocean's floor} =$$

M′C.

But this is also given directly, since $M'C = PC - PM' = 2.538 - \left\{\begin{matrix}1.8070\\1.7397\end{matrix}\right\} =$

$\left\{\begin{matrix}.731\\.7483\end{matrix}\right\}$ as before.

ocean waters are accumulated. On Mercury, and perhaps also on Venus, the intensity of the solar rays may prevent water from existing except in the form of clouds. Denudation, therefore, could not have begun. It is still quite conceivable, however, as before stated, that the freedom of radiation in the upper atmospheres of both these planets, and especially of Venus, may be such as to condense permanent envelopes of aqueous vapor and thus screen the surfaces of the planets from the severest intensity of solar radiation. In such case, there must be also some amount of precipitation and a corresponding amount of erosion.

Some reasoning as to the conditions which may have affected precipitation on the moon have been presented in the section devoted to the geology of the moon. It seems supposable that during a portion of the moon's non-synchronistic period vapors condensed, rains fell and seas of some extent existed. The great tidal influence experienced by that body, however, rendered it impossible that land masses should not be raised to great altitudes above the sea level. The enormous height of the tides in any extensive ocean must, therefore, have eroded the shores and the bottoms of shallows with intense energy. If the earth was still a sun to the moon, its heat must have caused an extraordinary amount of evaporation and consequent precipitation, and the agency would have eroded the uplands to a corresponding extent. Or, if water remained on the moon after the synchronistic period had been reached,— something which I have not assumed,—it fled to the farther side, but underwent most copious evaporation through solar influence during each alternate fortnight. Great evaporation implies great precipation; and it is hardly supposable that some of these rains did not fall on the land side, and thus serve as an efficient agent of erosion. But there is reason to doubt whether

the moon's surface in non-synchronistic times ever experienced sufficient composure to allow a proper ocean to rest upon it. Not improbably, the water, through the constant ruptures of the crust, and outbursts of molten matter, was kept in a constant process of evaporation and condensation, until the solidified portions became sufficiently voluminous to receive the water into their pores. In this case, the records of all aqueous erosions which ever took place on the moon have become obliterated or disguised by the violence and duration of eruptive action.

Mars is the only one of the planets besides the earth on whose surface aqueous erosions are somewhat certain to have taken place. The largest of the satellites of Jupiter, with a diameter of about 3700 miles, and the sixth of Saturn, with a diameter of 3300 miles, are both considerably larger than Mercury, and may easily be conceived to have passed a thermal condition suited to aqueous precipitation and erosion. But the enormous tidal power exerted on these satellites by their primaries renders still more probable than in the case of our moon, the hypothesis of incessant physical violence during their non-synchronistic period, and the absence of all proper aqueous erosion. But the improbability of erosion on these satellites appears still stronger when we perceive the probability that they are mere watery globes, or at least completely covered by icy crusts. On such globes, though precipitations of inconceivable copiousness must have taken place, they occurred in an epoch before the formation of the icy crust. After its formation there would be no longer any rainy precipitation or erosive movements of waters.

§ 2. PROGRESSIVE SUBSIDENCE OF TEMPERATURE.

The nebular theory implies that all cosmical spheres after having attained the temperature due to condensation, begin a process of refrigeration due to excess of radiation

over amount of heat resulting from continued transformation of mechanical energy. The consequences accompanying the process of cooling have been traced from the nebular to the habitable stage; and incidental references have been made to more advanced stages. Let us contemplate in a more orderly manner, some of the later incidents of cooling. So far as I have discovered, they reduce themselves to two categories.

1. *Shrinkage and Acceleration of Axial Motion.*—The earlier relations of shinkage to rotary acceleration have heretofore come under consideration. But after a planet begins to be encrusted the method and the rate of refrigeration are materially changed. In the fluid state, circulatory convection brings the hottest portions continually to the surface, and the escape of heat by radiation is rapid. After a crust exists, the fluid within is protected from direct radiation. Its heat imparted to the crust must be conducted through to the exposed surface before it can be lost to the planet. As the crust thickens, the difficulty of conduction increases, and hence the rate of planetary cooling diminishes. At a certain time the temperature of the exterior ceases to be elevated by the heat reaching it from within, since the radiation quite equals the amount of heat conducted to the surface. With the progress of time, the superficial zone of fixed temperature, save from climatic influences, deepens. This zone experiences no contraction from its own cooling, but receives a lateral pressure arising from the general cooling and shrinkage of the planet. The consequences of this are thought by some to be manifest in plications, crushing, folds and mountain saliences. A convective movement of the internal fluid, if any exists, may still be maintained, but it becomes more and more sluggish as the crust thickens. With a planet as thickly encrusted as the earth, the escape of heat is extremely slow, and hence contraction and axial

acceleration are slow. Calculations based on the recorded dates of ancient eclipses indicate, as Laplace thought, that the terrestrial day has not been shortened within 2000 years by more than a small fraction of a second. This, however, if true, is no disproof of the existence of a shrinkage process. The proper acceleration may have been compensated by one or both of two causes. *First*, the equatorial protuberance may have been prevented by the earth's rigidity from subsiding at such rate as to respond to the total shrinkage. The preservation of the equatorial diameter would largely conserve the rate of rotation. If the subsidence of the equatorial protuberance should proceed spasmodically, the irregularly varying oblateness of the earth might make itself felt in irregularities of the lunar motions and in the precession and other movements connected with terrestrial oblateness. The *second* cause compensating the effect of contraction is the influence of the tides, to which reference will shortly be made.

If we had information concerning the actual temperature of the earth's interior, it would be possible to calculate, under certain assumptions, the total amout of shrinkage which might result from any future refrigeration.

2. *Absorption of Water and Atmosphere.*—I have already referred to the probably absorbed condition of the lunar ocean and atmosphere, and appended in a note the requisite formulæ for ascertaining the depth of crust demanded for such absorption on any planet constituted with solids and fluids in the same proportion as the earth, when the value of certain constants has been ascertained by observation. The earth is the only planet on which observation enables us to ascertain directly the values of all the constants. Those accessible only to direct observation are the following:

(1.) The index of rock absorption by volume. By this is meant the volume of water absorbable by one volume of

the rocky crust of the earth. This can only be determined by experiments on rock substances occurring near the earth's surface. Such experiments have been made by Durocher,* Hunt and others.† Two methods have been employed, one direct, the other indirect, or by inference from the amount of condensation experienced in solidification or through hammering. Durocher experimented on those minerals which enter most commonly into the constitution of rocks, such as feldspars, micas, hornblende and pyroxene. The minerals were reduced to coarse powder and exposed to moist air. The amount of water absorbed was found by weighings, and the results were as follows: The orthoclase of Utoë absorbed .0041 parts by weight; seven other varieties of orthoclase absorbed .0128 parts; thirty specimens of various minerals absorbed, on the average, .0127 parts. A large number of determinations of the absorptive properties of building stones was made by a committee of the British House of Commons and reported in 1839. This committee, of which the celebrated geologist Henry de la Beche was a member, employed blocks of an inch cube, which were thoroughly soaked in water under the receiver of an air pump, and subjected to the requisite weighings. The following are some of the results reduced to absorption by volume:

3 Silicious Limestones, .053, .085, .109.

4 Nearly pure Limestones, .180, .206, .244, .310.

4 Magnesian Limestones, .182, .239, .249, .267.

6 Sandstones, .107, .112, .143, .156, .174, .221.

Similar experiments were made by Professor T. Sterry Hunt on Canadian rocks, in 1864.‡ Dr. Hunt took small

* Durocher, *Bull. Soc. géol de France*, II, x, 131.

† See a report on Building Stones made to the British House of Commons in 1839, by Barry, de la Beche and Smith.

‡ T. S. Hunt, *Amer. Jour. Sci.*, II, xxxix, 183, March, 1865; *Geology of Canada*, 1865, 281–4; *Canadian Naturalist*, February, 1865, 10; *Chemical and Geological Essays*, 164.

broken fragments of the rocks — generally from 300 to 600 grains in weight — carefully freed from adhering loose particles, dried them at 200° Fahr. until they ceased to lose weight; noted their dry weight, left them in contact with water for some hours, and then kept them immersed in water under the exhausted receiver of an air pump until all bubbles disappeared; removed them and wiped off superfluous water with blotting paper, and finally weighed them, first in air and then in water. These weighings furnished the data for calculating, among other results, the index of absorption by volume. The results of these experiments on 39 varieties, mostly of stratified palæozoic rocks, are published. A general view is given below:

4 Potsdam Sandstones, hard and white, .0139 to .0272.
2 Medina Sandstones, .0837 to .1006.
3 Devonian Sandstones, .2024 to .2127.
5 Shales, .0075 to .0794.
6 Limestones, .0030 to .0527.
11 Dolomites, .0215 to .1355.
3 Tertiary Limestones, .2693 to .2954.

Nearly all these experiments relate to the absorbent properties of stratified rocks, and the results cannot be taken as expressing the absorbent power of the cooled crystalline crust of the earth. Some extended experiments published by Dr. Hiram A. Cutting,* State Geologist of Vermont, include, among other rocks, 22 varieties of granite. His method of procedure was similar to that of Dr. Hunt. He used samples about three by four inches, and two inches thick. His specific gravities are those of

* H. A. Cutting: *Weight, Specific Gravity, Rates of Absorption and Capabilities of Standing Heat of Various Building Stones*, Science, i, 254-6, November 20, 1880. Dr. Cutting's results on the effects of heat possess great practical interest. In this connection, consult also Gen. Q. A. Gilmore's *Report of the Compressive Strength, Specific Gravity and Ratio of Absorption of the Building Stones of the United States*, 8vo, 57 pp., 1876.

the particles of the rock or true specific gravity, and not of the gross bulk of the samples. The true specific gravities of his samples range from 2.526 in a light-colored granite from Oak Hill, Maine, to 2.833 in a light-colored granite from Stanstead, Canada. The general mean is 2.625. The absorption of one part, by weight, of water, required weights of granite ranging from 280 in a light-colored granite from St. Cloud, Minnesota, to 818 in a gray granite from Croton, Connecticut.* The mean absorption was one part of water for 610 parts of rock by weight. The celebrated Quincy granite (syenite) stands near these means, having a specific gravity of 2.660 and an absorbent power expressed by 650. From these observations it appears that the mean index of absorption by volume is .004303.†

*Thus the most absorbent granite was not the one with lowest specific gravity; nor the least absorbent, the one with highest specific gravity. This would result from the different *proportions* of the lighter and heavier mineral constituents in the different granites.

†As the mean amount of water absorbed by one part of granite is $\frac{1}{6}\frac{1}{1}\frac{1}{0}$ by weight, and the mean specific gravity of the granite is 2.625, the mean volume of water absorbed by one volume of granite is $\frac{1}{6}\frac{1}{1}\frac{1}{0} \times 2.625 = .004303 = i$.

We may readily deduce general formulæ for the various results determinable from the weighings before mentioned.

Let a = weight of dried rock.

b = difference of weights of dried and saturated rock = weight of water which the rock is capable of absorbing. Represents the *porosity* of the rock.

c = loss of weight in water, of saturated rock = weight of volume of water the same as the gross volume of the rock. Represents the *gross volume* of the rock.

Also $c - b$ = weight of water displaced by net substance of the rock.

Then $\frac{a}{c}$ = *specific gravity* of the gross rock,

$\frac{a}{c-b}$ = *specific gravity* of the net rock,

$\frac{b}{a}$ = index of absorption by weight.

Also, since volumes are directly as weights and inversely as specific gravities,

$$i = \frac{\text{volume of water absorbed}}{\text{gross volume of rock.}} = \frac{\text{weight of water absorbed} \times \text{sp. gr. of rock}}{\text{weight of rock} \times \text{spec. gr. of water.}}$$

$$= \frac{\frac{ba}{c}}{a} = \frac{b}{c} = \text{index of absorption by volume.}$$

Attempts have been made by Bischof and MM. Charles Ste. Claire Deville * and Delesse † to obtain the difference of porosity of the same substances in the liquid and crystalline states and thence to infer the absorbent properties. MM. Deville and Delesse showed that granite on fusion yields a glass having a density from .09 to .11 less than that of the granite. This means, supposing the gross volume to remain the same, that a granitic glass when crystallized increases the net specific gravity of its substance, and must inclose pores in its structure to a corresponding extent; that is, to about one-tenth of its gross volume. Taking the mean density of granite at 2.625, it would, with such porosity, imbibe .03809 parts by weight for each part of granite.‡ On similar principles, Dr.

The following forms are sometimes more convenient:

Let s = weight of saturated rock,

s' = weight of saturated rock in water.

Then $b = c - a$; $c = s - s'$ and $c - b = a - s'$.

Whence $\frac{a}{s - s'}$ = specific gravity of gross rock,

$\frac{a}{a - s'}$ = specific gravity of net rock,

$\frac{s - a}{a}$ = index of absorption by weight,

$\frac{s - a}{s - s'}$ = index of absorption by volume.

* Deville, *Comptes Rendus*, 1845.

† Delesse, *Bulletin Soc. géol. de France*, 1847, II, xix, 64.

‡ Some general expressions for converting such relations will often be found convenient.

Let g = specific gravity of a rock, water being 1,

m = weight of water absorbed by unit weight of rock,

n = volume of water absorbed by unit volume of rock.

Then mg = volume of water absorbed by unit weight of rock.

Assuming unit weight of rock as unit volume of rock,

$$n = mg \therefore m = \frac{n}{g}, \text{ and } g = \frac{n}{m}.$$

Hence, further, by *Weight*,

If rock is 1, water absorbed is m.

If water is 1, rock absorbing it is $\frac{1}{m} = \frac{g}{n}$.

And, by *Volume*,

If rock is 1, water absorbed is n.

Frankland has calculated that the moon in cooling through 180° would create cellular space equal to 14,500,000 cubic miles.* In cooling throughout from a liquid to a solid state, supposing the liquid to be represented in density by the solid glass, the moon would acquire, according to the ratio of porosity found by Deville and Delesse, 528,000,000 cubic miles of porous space.†

Sæmann has pursued another indirect method for obtaining the amount of porosity acquired in passing from the liquid to the solid state. He assumes that the porosity of the metals is due to molecular shrinkage experienced in cooling, and that the condensation produced by hammering is the measure of such shrinkage. Calculating from the increased density of various metals produced by hammering, he finds that the porosity of cast iron is .075; nickel, .045; aluminium, .041; copper, .011; gold, .005. These results accord sufficiently well with those obtained by Deville and Delesse.

It is doubtful whether these methods are suited for obtaining the absorbent properties of rocks. It is even highly probable that all liquefied substances diminish in specific gravity in the act of solidifying; though, as before stated, they may acquire, on further cooling, a density greater than that of the liquid magma. The assumed shrinkage which is supposed to create porosity is probably the normal shrinkage due to reduction of temperature considerably below the point of solidification. The porosity inferred is ten times as great as that indicated by direct experiments on absorption. M. Sæmann's assumption also is quite gratuitous. At least, it affords no criterion of the

If water is 1, rock absorbing it is $\frac{1}{n} = \frac{1}{mg}$.

If $n = .1$, $m = \frac{n}{g} = \frac{.1}{2.265} = .03809$.

* Frankland, *Proc. Roy. Inst.*, iv, 175.

† $\frac{4}{3}\pi \times (1080)^2 \times .1 = 527,870,000$ cubic miles.

absorbent properties of the metals. This is shown not only by the want of any cited justification of the assumption, but by the fact that the result is ten times as great as direct experiment produces.

It is safest, then to resort to direct experiment, and the index of absorption calculated from Dr. Cutting's weighings must be regarded as the best present approximation to the absorbent power of the terrestrial crust. This is, $i = n = .004303$.

(2.) The volume of the ocean. This depends on the superficial extent and the mean depth. The ratio of the total land surface of the earth to the total ocean surface is generally stated as 1 : 2.75. In other words, the land surface is represented by .267 and the ocean surface by .733. This is the ratio given in the *Annuaire* for 1881, and the ratio here adopted. Herschel puts the ratio at 1 : 2.86, since the total water surface is estimated at 146,000,000 miles and the land surface at 51,000,000.* Professor Haughton puts the area of the sea at 145,000,000 square miles, and the land at 52,000,000, which gives a ratio of 1 : 2.79.† Dr. Carpenter adopts the ratio of 1 : 2.78.‡

The mean depth of the ocean can only be approximated. M. Sæmann, in his paper already quoted, assumes it as 600 metres, or 1,968 feet, which is a manifest underestimate. The results of the Challenger and earlier soundings combined together, give for the mean depth of the North Atlantic, about 2,600 fathoms; for the South Atlantic, about 1,900 fathoms; for the equatorial Atlantic, 2,000 fathoms, making for the general mean of the Atlantic, 2,166 fathoms.§ The mean depth of the Pacific between

*Herschel: *Physical Geography*, 2d ed, 19.

†Haughton, *Proc. Roy. Soc.*, vol. 26, p. 53, 1877.

‡W. B. Carpenter, *Encyc. Brit.*, Art. "Atlantic Ocean."

§ This was written before learning Sir Wyville Thomson's estimate as stated in his Rede lecture at Cambridge in 1877. He makes the mean depth of the Atlantic about 2,500 fathoms, and this opinion is probably as near the truth as we can come.

Japan and San Francisco, according to the calculations of the United States Coast Survey, based on the transmission of an earthquake sea wave, is 2,300 fathoms. Calling this the mean depth of the Pacific, and giving the number equal weight with that for the depth of the Atlantic, as found above, the mean depth of the two is 2,233 fathoms, or 12,398 feet, or 2.538 miles, which may be provisionally assumed as the mean depth of the general ocean. This is 6.8 times as deep as assumed by M. Sæmann.

(3.) Calculation of absorptive capacity of the planetary pores. Having the area and mean depth of the ocean, we may ascertain its cubic contents; then, knowing the index of absorption of the earth's crust, a simple application of the general formula before deduced (p. 382) gives the thickness of cooled crust requisite to effect the absorption of the ocean. Many circumstances may render the absorbent property of the deep crust different from that of surface rocks. Any residual heat above the temperature at which experiments have been made would probably diminish the power of absorption. On the contrary, great condensation of the water might take place, either through the physical action of minute pores, or the great pressure of superincumbent matter. In the present state of knowledge, we can only assume that the absorbent property of the crust is about that of the superficial rocks. Employing the index of absorption given by Dr. Cutting's experiments, and neglecting the superficial zone already saturated with water, our formula gives 490.8 miles as the thickness of the terrestrial zone, which would retire all the water now filling the ocean's basin. If we wish to know what thickness of zone below the zone already saturated would suffice to absorb the ocean, we may employ first the formula given for obtaining the thickness of the saturated zone. In this, if we assume the rate of increase of temperature downward to be one degree for 50 feet; the

mean temperature at the surface, 47°; the temperature at which water vaporizes in the crust of the earth, 212° Fahr., and the depth to constant temperature, 80 feet, the saturated zone is shown to be 8,330 feet or 1.5776 mile. Employing this value in the general formula, we find that a zone 491.42 miles thick within the present saturated zone would absorb the ocean's water.

According to M. Sæmann's calculations, the pores of the rocks of the totally refrigerated earth, after having taken in the waters of the ocean, would amply suffice for the absorption of the atmosphere also. But I have shown that he has assumed a depth for the ocean which is over eight times too small, and, on the contrary, an absorbent property of surface rocks which is ten times too great. Accordingly, it does not appear that this porosity is sufficient for the total retirement of the water and air. Taking Sir John Herschel's mass of the atmosphere (reduced to surface density, $\frac{1}{1200000}$), its relative volume is .003837; and application of the formula adapted to this case (p. 383, note) shows that this is more than the capacity of the pores would receive after the absorption of the ocean. This is evident, indeed, from the fact that the ocean would appropriate .3276 of the earth's total capacity, leaving only 2.052 times this amount unappropriated, while the relative volume of the ocean being .001409, the relative volume of the atmosphere (.008837) is 2.723 times that of the ocean. It is entirely probable, however, that absorbed air would undergo a sufficient condensation to render the whole atmosphere absorbable. Supposing a somewhat free communication among the pores, columns of air would exist reaching from the zone of the absorbed water to the earth's surface, which would be 1,230 miles. Now the whole depth of the atmosphere reduced to density of surface air would be but five miles. At half the depth of the zone left unoccupied by the

ocean — that is, at 615 miles — there would exist, making no allowance for diminished gravity below the surface, a pressure of 123 atmospheres, which would condense the air into 123 times less than its surface volume. If anything should interfere with the application of Mariotte's law, it would be an attraction for the air which would produce an equal or greater effect; as in the case of the condensive absorption exerted by charcoal, platinum-sponge and some meteoric stones. This method of calculation, however, assumes erroneously that each additional five miles of depth adds one atmosphere to the pressure. But as gravity beneath the surface of the earth varies as the distance from the centre, the pressure at the bottom of 615 miles would be only 104 atmospheres, and at the depth of 1,230 miles, 208 atmospheres.* There can be no doubt, consequently, after this correction, that the condensation would be sufficient, and much more than sufficient, to permit the final withdrawal of the terrestrial ocean and atmosphere.

As to the remoteness of the epoch when the earth's water and atmosphere will have been absorbed, little can

* Let r be the earth's radius and $5x$ be the depth beneath the surface, then the pressure due to successive five-mile zones will be expressed in terms of one atmosphere, as follows:

$$\frac{r-5}{r}, \frac{r-5\times 2}{r}, \frac{r-5\times 3}{r}, \frac{r-5\times 4}{r}, \ldots\ldots \frac{r-5x}{r}.$$

The last term expresses the pressure due to the last five miles. The pressure due to the middle five miles is $\frac{r-\frac{5}{2}x}{r}$, and this is the mean pressure in the whole series of zones.

If $5x = 1{,}230$ miles, the mid pressure is

$$\frac{3963-615}{3963} = .844 \text{ atmos.} = \text{mean pressure.}$$

The pressure due to the lowest five-mile zone is

$$\frac{3963-1230}{3963} = .689 \text{ atmosphere.}$$

The total pressure at the bottom is

$$\frac{1230}{5}\times .844 = 207.624 \text{ atmospheres,}$$

and the pressure at the bottom of a column half as high is half as great.

be said. In Mars we have a planet whose terrestrial stage, according to our theory, would have been reached 9,500,000 years ago, if we suppose its incrustation to have begun when the earth's began, and use the table of time ratios heretofore given. Since that epoch Mars has continued to advance in its evolution at a rate two and a half times as rapid as the earth, and yet Mars has not attained the stage of complete atmospheric absorption.* That is, if the evolution of the earth can be compared with that of Mars, it will be more than 24,000,000 years before the earth's atmosphere is absorbed. And to this must be added the difference in age of the two planets. On the other hand, assuming the same time ratios as before, we may reason from the condition of the moon, and, adopting 14,000,000 years as the earth's incrusted age, the moon reached the terrestrial condition 11,666,666 years ago. The advance of the moon in its evolution since that epoch is equal to the advance to be made by the earth in 70,000,000 years. But the moon's atmosphere is absorbed, and hence within 70,000,000 years the absorption of the terrestrial atmosphere will be effected. That is, reasoning from the slender data within reach, the absorption of the earth's atmosphere will be effected in a period lying between 24,000,000 and 70,000,000 years.

The secular disappearance of the surface waters of the

*It will be noticed that all the calculations made in reference to the absorption of planetary water and air assume a planetary density equal to the mean density of granite (2.625). But the deeper portion of the earth has a much higher density, and hence, probably, possesses a lower index of absorption, and would not, consequently, be able to effect all the absorption attributed to it in the text. Similarly, the moon, though its density is only .607 compared with earth, exceeds granite in density, and would have a lower absorptive capacity than we have attributed to it. Mars, also, with a mean density (.6481) a little greater, is more dense than granite, and with a presumably larger proportion of water and air, might be supposed incapable of completely absorbing its surface fluids; so that, after all possible absorption is effected, a residual portion of the Martial atmosphere (if not of water) will remain permanently. This consideration bears on the inferior limit of time within which the earth's atmosphere may be absorbed. That is, it may *not* be "more than 24,000,000 years."

earth is a fact of observation and record. The ocean was once universal; it is in our times withdrawn from three-tenths of the earth's surface. This is generally attributed to the progressive increase of the inequalities of the terrestrial surface; and it is not possible to disprove the position. But there are many indications of a slow desiccation of the land during human occupation. Lakes have disappeared or diminished; marshes and alluvial areas occupy situations once water-covered. Climates have become more arid; and many regions once productive have become sterile and uninhabitable. Numerous illustrations of these statements are familiar to every intelligent person. I have been accustomed for fifteen years to discuss the subject in my university lectures. No one, however, has given the facts so much consideration as Professor J. D. Whitney; and after directing the attention of the reader to the interesting phenomenon, I must refer him for the abundant facts, to Professor Whitney's writings.*

To the present probable condition of the moon I have had frequent occasion to allude. That its surface is destitute of air and water is generally admitted. M. Faye maintains that these fluids were never present; but it is impossible to adopt any theory of the origin of the moon by derivation from the earth or from a common mass with the earth, and deny the necessity of aqueous and atmospheric

*J. D. Whitney: *American Naturalist*, x. 513, September, 1876; Memoirs, Museum of Comparative Zoölogy, Cambridge, Vol. vii, On *Climatic Changes of Later Geological Times*, Part I, 120 pp., 1880; Part II, 121–264 pp., 1882, Part III, 265–394 pp., 1883. See also *Amer. Jour. Sci.*, III, xx, 460, xxiii, 489–90, xxv, 153. For some shrinkages of American lakes, see King: *Geology of the 40th Parallel*, i, 490–504; Stevenson, in *Wheeler's Report*, iii, 453–71; Howell, *ib.*, 250–1; Hayden, *Report on Wyoming*, 1870, 72–3 and *Annual Report* for 1874, 48; *Pacific R. R. Report*, ii, 97; Endlich, *Hayden Report*, 1875, 147–8; *Nature*, xxii, 41; A. R. C. Selwyn: *Geol. of Canada*, 1873–4, 27, 58; C. Robb: *Geol. of Canada*, 1874–5, 53–6. Compare also, A. Winchell, *Trans. Mich. Agric. Soc.*, 1865; *Syllabus of a Course of Lectures on Geology*, 1869, 7, *ib.*, 1870, 12; *ib.*, 1874, 20, 24; *ib.*, 1879, 44, 112; *Amer. Jour. Sci.*, II, xxxviii, November, 1864; *Sketches of Creation*, 1870, 237–9.

constituents. The apparent absence of such fluids can only be explained on the theory of their complete absorption.

By the logic of our theory we are constrained to believe that water and air have disappeared from the surface of every body in our system, of greater age than the moon, and not much surpassing it in size, provided its solids and liquids were originally proportioned somewhat as in the moon and earth. But according to our theory also, all the older bodies must have received a larger proportion of fluids than the earth. The water surface of Mars must have been in larger ratio than on the earth, and the Martial atmosphere must have been more voluminous. Then, perhaps, Mars might become completely refrigerated without absorbing all its water. Still more likely, a surplus of atmosphere would remain. That a full supply of water and air is not present is manifest from the comparatively unclouded condition of the disc of the planet. In this view, the indications of an atmosphere will never disappear from Mars. It may have been senescent and refrigerated for millions of years — as indeed our moon may have been. As to the Martial satellites, it cannot be doubted that they have long since attained their final condition, so far as concerns heat and absorption of fluids; and that cannot be far different from the condition of their primary.

The asteroids should present a still further divergence from the conditions of the earth. They are probably ice-covered and frozen to the core, each retaining an abundant quota of atmosphere.

Jupiter, I have assumed, in consequence of his enormous mass, to be still far short of the terrestrial stage. The large percentage of fluids in his constitution renders it improbable that any considerable land surface should ever emerge; and still more improbable that the fluids should ever become completely absorbed. Jupiter's glacier-

clad satellites present the picture of Jupiter's remote future destiny.

In the ultra-Jovian planets this destiny is attained. All fluid absorption of which they are susceptible is a finality long since attained in each of the three successively. They are globes of solid ice, inclosing cores of rocky material, and wrapped in vapor-laden atmospheres. (See chapter iii, § 6.)

Looking in the other direction, it may be suggested that Venus and Mercury, in consequence of their diminished proportion of fluids, will become desiccated and airless at a relatively earlier age than the earth. That they are not yet so is indicated by the envelopes of vapor which conceal their discs from view.

§ 3. SYNCHRONISTIC MOTIONS AND TIDAL FINALITIES.

It appears that tidal influences have performed a part of prime importance in the evolution of worlds. I have had former occasion to explain these influences upon the rotation of cosmic bodies, and have pointed out the tidal interactions of the earth and moon and of the sun and planets. The subject comes again into view in connection with the ulterior vicissitudes of planetary bodies which we are now grouping in a connected presentation.

Directing our attention first to the interactions in which the earth is concerned, we perceive that the tidal retardation which it is destined to experience will first bring about synchronism between the day and the lunation. The earth and moon will turn permanently the same sides toward each other, and the two will rotate as parts of a rigid system about a common axis. The reaction of the earth upon the moon will have caused it to recede to the distance of about 347,100 miles, and the lunation will, accordingly, have been lengthened to 48.36 days.*

*Thomson and Tait: *Treatise on Natural Philosophy*, 2d ed. § 276. The tidal retardation of the earth's rotation was first suggested by Kant, in 1754.

The tidal retardation of the earth's rotation, that is, the gradual lengthening of the day, is a fact of observation. The number of seconds since the occurrence of an ancient eclipse, for instance, would be somewhat less than calculation shows, if the day, and hence the second, has been slowly lengthened. The subject was investigated by Laplace, on the basis of eclipse observations recorded by Hipparchus, 720 B.C., and shows that the length of the day had not increased one ten-millionth of itself, or $\frac{1}{1\,1\,5}$ of a second, in the intervening time. But Adams, in 1859, pointed out an oversight in the investigation of Laplace on the acceleration of the moon's mean motion, showing that one-half of its apparent acceleration, relatively to the angular velocity of the earth's rotation, remained unexplained. That is, the moon was 5″.7 in advance of the position she would have relatively to a meridian on the earth at the end of a century, after all known disturbing causes had been taken into account. This is the same in effect as if the earth in her rotary motion were a little behind, and Delaunay soon showed that this was probably the true explanation. Investigating the amount of tidal retardation of the earth's axial velocity due to the influence of both sun and moon, and allowing for the retardation of the moon by reaction of the lunar tide, he found that the earth's meridian was behind the position required by the lunar motion, by just about the amount of the tidal retardation. Thus it appears that the terrestial day is shortened about twenty-two seconds in a century, and tidal action is the cause.* Should this rate of retardation continue, and should the length of a lunation not change, a state of synchronism would be attained in about 378,000 years. But the rate will be diminished, both by the slow recession of the moon and by the growing infrequency of the tide.

*But on the contrary, see E. J. Stone, *Proc. Roy. Soc.*, Apr. 12, 1883, *Nature*, xxviii, 71.

The length of the lunation will also be gradually increased.

After a state of lunar-terrestrial synchronism shall have been attained, it cannot remain undisturbed through the indefinite future. The solar tide still exists, though it recurs only once in forty-eight days, with the antitide intervening. This tide also lags, and the sun's action upon it yields a tangential component against the rotation of the earth, tending to reduce the earth's rotary motion below the rate of the moon's orbital motion. That is, in course of time, the lunar tide, instead of being ahead of the moon's position, will be behind it, and the moon and sun will contend for the control of the earth's rotation. The sun will strive to lengthen the day and the moon will now strive to shorten it. The reaction of the lunar tide will now retard the moon's motion, and centripetal force will gain a slight ascendancy. As a consequence, the moon will approach the earth and will ultimately be precipitated upon it.

Meantime, the tidal interactions between the earth and sun repeat those between the moon and earth. The lagging of the terrestrial tide on the sun, acted on by the earth, tends to equalize the sun's rotation and the earth's revolution. The reaction of this tide on the earth's motion increases the distance between the earth and sun, and the lagging solar tide on the earth, acted on by the sun, continually diminishes the rotary velocity of the earth, and (through the displacement of the lunar tidal protuberance) the orbital velocity of the moon, thus accelerating the precipitation of the moon on the earth. As an outcome of this contest between the moon and sun, if I reason correctly, the day will become a little longer than the lunation, so that the lunar tidal protuberance will exist continually a little behind the moon's position, and the solar tidal protuberance a little ahead of the sun's position, so placed that the accelerating influence of the moon

will be exactly balanced by the retarding influence of the sun. Thus the moon will perpetually approach the earth, and the earth will perpetually recede from the sun. But when eventually the moon falls to the earth, the solar tide will bring the latter to such a rate of rotation that the day will equal the (lengthened) year; and with no further interferences, this state of rotation would continue forever.

If we consider the ultimate tidal history of Venus, it is manifest, on grounds before explained, that so long as fluids exist on the surface of the planet, or so long as a state of incomplete rigidity remains, a solar tide will exist, whose lagging must furnish the condition of a tangential component opposing axial rotation. Venus will therefore be reduced to a state of synchronism, and will revolve at an increased distance from the sun. Simultaneously the tide raised on the solar surface will offer the conditions of solar rotary retardation, and neglecting the influence of other planets, Venus and the sun will finally rotate as a rigid system around their common centre of inertia. The tidal influence of Venus upon the sun is two and a third times as great as that of the earth; hence the sun will obey Venus at first, and arrive at synchronism with that planet. Then, as the rotary velocity of Sun-Venus will exceed the orbital velocity of the earth, the geal tide raised on the sun will be in advance of the line joining the centres of the earth and sun, so that the tangential component of the earth's action on the solar geal tide will be retardative, and the sun will tend toward synchronism with the earth. The sun's tidal reaction on Venus will now be retardative, and Venus will approach the sun. The remote tidal interaction with Mercury will be similar. It may be noted also that the tidal control exerted by that planet over the rotation of the sun will be to that exerted by the earth as 1.118 to 1.

There is ground for believing that the rotary motions

of all the satellites of our system have long since become synchronistic with their orbital motions. In a system embracing numerous moons, like Jupiter's, each satellite produces its separate and independent effect, and these are always concurrently retardative. In some distant age the rotation of the planet will become coincident with the revolution of the nearest satellite. The retardative action of this will then cease, and the retardation will continue under the influence of the other satellites, toward the attainment of synchronism with the second satellite. But meantime the first satellite has a greater angular velocity than the planet, and the relation of Phobos to Mars is realized. It tends now to accelerate the rotation of the planet. The reaction of the planetary tide on this satellite retards its motion, and brings it on a course of precipitation in a spiral path upon the planet. At length synchronism with the second satellite is attained, and its history repeats the history of the first. Ultimately, all the satellites except the last are precipitated on the primary, and the planet's rotation attains synchronism with its revolution. Theoretically the sun must be viewed as still further retarding the planet's rotation by action on the lagging solar tide; and this tide reacting on the last satellite, retards it and accomplishes precipitation on the planet. Finally, disregarding the presence of other planets, this planet and the sun attain synchronistic motions, as in the case of the earth-sun. The tidal action of the sun, however, upon the major planets is so slight relatively that the events contemplated are removed to a future excessively remote, and we may fairly expect them to be forestalled by other eventualities.

§ 4. ULTIMATE INFLUENCE OF INTERPLANETARY RESISTANCES.

The analogies of nature and the ascertained facts of physical science forbid us to doubt that every one of them — every star and every body of every

kind, moving in any part of space—has its relative motion impeded by the air, gas, vapor, medium, or whatever we choose to call the substance occupying the space immediately round it.—SIR W. THOMSON and P. G. TAIT.

It is a common remark that Laplace found the harmony of the solar system stable, provided that interplanetary space is a vacuum, and the planets themselves are perfectly rigid bodies. More recent science has shown that neither of these conditions of indefinite stability exists. Occasions have arisen in other connections, to point out many of the facts which contravene the conditions of stability, but it will be useful to summarize in due connection the indications of eventual conglomeration around centres of orbital motion. Were the planets all as solid as granite, there would exist sufficient plasticity to yield a tidal protuberance under their mutual actions and that of the sun. It was shown in the last section that tidal actions and interactions affect both rotary and orbital motions; and that under certain circumstances, mere tides tend to precipitate planetary masses upon their centres of motion. The freer the mobility of certain parts of a tide-bearing body, the more efficient this action, provided some of the other parts are relatively much more rigid, to furnish points of resistance to the parts tidally moved. But probably no matter exists so completely rigid as not to undergo relative displacement in the presence of the tremendous forces exerted by planetary and solar masses. Hence, on planets not covered by waters, and on planets whose seas have been converted into ice, tidal action continues, and tidal finalities are impending. Such results flow from the absence of complete planetary rigidity.

A more commonly recognized cause of a tendency toward central precipitation is the presence of resisting or colliding matter in the interplanetary spaces. In another connection * I have discussed the diffusion of meteoroidal

* Especially in Part I, ch. i, § 6.

matters and of other possible forms of matter consisting of gases, vapors or ethers, and have reached the conclusion that space is so far from the condition of a vacuum that it seems rather to be a plenum, the contents of which necessarily interfere with all relative motions in the universe. The conception of an extremely attenuated material medium has been entertained ever since the time of Sir Isaac Newton, and many eminent authorities have felt great confidence in its reality, and have discussed its necessary properties — sometimes holding it to be a continuous fluid, and in other cases considering it rather to have an atomic or discrete constitution.* It is impossible that an ethereal medium, however tenuous, should exist without impressing results on the motions of cosmical bodies. This influence has been thought detected in the accelerated angular velocities of Encke's and Winnecke's comets, particularly the former, which moves throughout its whole course in an orbit relatively not remote from the sun. The ethereal medium is generally assumed to diminish in intensity with increase of distance from the sun. The assumption that the density varies inversely as the square of the distance agrees best with observation on the cometary effects of supposed ethereal action. The formulæ expressing these perturbative effects show that the tendency of the medium, conjointly with solar attraction, would be to continually accelerate the mean motion and diminish the eccentricity of the orbit. Accelerated motion arises from diminished distance from the sun. If these conclusions are correctly based, we are therefore enabled to make actual observation of the slow spiral approach of a body toward its centre of motion. It must be said, however, that the later movements of Encke's comet do not clearly sustain the theory of slow precipitation, and some high physical au-

*We might add to the citations heretofore made (p. 52) Kretz: *Matière et Ether; indication d'une méthode pour établir les propriétés de l'Ether.*

thorities deny that its entire observed history favors the doctrine of precipitation, or lends any distinct evidence of the existence of a resisting medium.* If, however, the earlier and later observed movements reveal irregularities in the motion of the comet which cannot be ascribed to planetary perturbations, it is allowable to suspect that the temporary and unknown cause of irregularities will hereafter cease to act, and the subsequent accelerated motion of the comet reveal with increased distinctness the presence of a resisting medium. But whether human skill, in the course of one or two generations, shall succeed or not in discovering the effects of a resisting medium, we must admit that the effects are real, or incur all the embarrassment of ignoring the existence of any vibratory medium for transmitting the radiations of the sun and other heavenly bodies. If we admit, even in theory, the existence of a universal material fluid, we must admit, as a consequence, the ultimate precipitation of the planetary bodies upon their centres of motion.

I have heretofore expressed the opinion that another cause exists in space adequate to exert the resisting action generally ascribed to the ethereal medium. That cause is meteoroidal. It is easy to conceive that a perturbation proceeding from this cause would produce a mean effect equivalent to that of a resisting force acting in the tangent to the instantaneous orbit; and that the amount of the perturbation or resistance should increase as the distance from the sun diminishes. It seems to me that a disturbance of this nature is more clearly established than the resisting property of the ethereal fluid.

* Dr. Backlund, of Pulkowa, concludes from an investigation of the motion of Encke's comet that "if there exists a tangential force which varies with the dimensions of the comet's orbit, its effect is not only secular but periodic." His investigation proves that the acceleration of the mean motion in the period 1871–81 was less than half the value found by Encke and Asten for the period 1819–65 (*Nature*, xxviii, 181). This is the latest announcement on the subject.

Many trains of investigation lead toward the conviction that space is pervaded by some condition of matter in a state of general dissemination. The intimation has recently come to us through the researches of Captain Abney, that the vapor of water and hydrocarbon compounds are possessed of a general distribution. The latter, at least, had been already detected in comets and in meteoric stones. It is equally probable that hydrogen helps to fill the void between us and the sun; and no improbability is apparent that the very atmosphere which we breathe stretches on indefinitely toward the stars, diminishing ever in density as we recede from the earth, but increasing in density as we approach other bodies, and constituting an intelligible material intermedium. One can imagine what extreme tenuity such a medium must possess in the interplanetary spaces when it is considered that the meteoroids moving through it at the rate of forty miles a second do not develop heat more rapidly than the power of radiation in the regions which they traverse is capable of conveying it away.

By some cause acting after the manner of a resisting medium certain comets seem to have been impressed. By such a cause the satellite Phobos may have been impressed, for it appears to be in actual course of precipitation. By some similar cause or causes all the planets and satellites must be slowly affected; and our inability to discern and measure the results may be well ascribed to their minuteness within human periods, and the effect of other perturbative causes in disguising them. It appears to be generally admitted that precipitative tendencies exist, and none of the eventualities of the distant future will be able to annul them. We therefore conceive of the ultimate return of the various members of the sun's family back to the central mass from which they originally sprang.

We observe in the Solar System a mode of action which in principle is the same as that of interplanetary matter; but the action is exerted by matter which constitutes a part of the aggregation acted upon. It exists in cometary and meteoroidal trains, in the rings of Saturn, and probably in the zodiacal light — possibly, also, in the swarm of asteroids and in other groupings of cosmical particles and masses. It is not conceivable that the parts which constitute the head or even the tail of a comet, for instance, stones, grains, dust, vapors, move with such uniform velocities and directions as not to collide with each other. I have heretofore, following Sir William Thomson, ascribed the evidences of a gaseous glow in the head of a comet to the collisions of the stony constituents of which it is composed. Where mean velocities are fifty or one hundred miles a second, it requires but slight differences of velocity to produce relative velocities equal to those of military projectiles. A cannon ball moves 1,400 to 2,000 feet in a second, and yet its impact upon a solid body always develops a flash of light. But this velocity is mere rest when compared with that of a comet in its flight. Now, in case of these mutual collisions among the parts of a comet, the velocities of some will be accelerated and those of others retarded. Those retarded are liable, of course, to be accelerated again by other collisions, so that the total amount of motion in the assemblage should remain constant, so far as actions in the system are concerned. Nevertheless, the changed velocity of a part results in a changed intensity of action from without. Retardation results in an increase of centripetal tendency, while acceleration results in an increase of centrifugal tendency. The accelerated and retarded parts, therefore, tend to separate from each other, and thus coming into changed relations to an external action, are further separated. In the nearer proximity of a great

attractive mass, as when a comet passes near a planet, these changed relative distances of the cometary parts from the mass enable the latter to wrench the comet's constitution to a destructive extent. The effect is an incipient disintegration—a dispersion of the parts and the commencement of their precipitation upon the disturbing body. The meteoroidal stage of a comet's life exemplifies the progress of the disintegration; and the meteoroidal swarm itself must be regarded as going to pieces through the continuance of these internal and external actions.

As the rings of Saturn are probably mere cosmical atoms, quite as hard and discrete as those existing in comets and meteoroidal swarms, there is equal reason to suppose them also subject to mutual collisions. In such case, the parts suffering retardation would approach the planet and circulate with restored and even increased velocity, in nearer proximity to it. Thus certain particles of the Saturnian rings should continually transfer themselves from other regions to the inner margin of the ring system. The ring system should slowly, molecularly, grow inward and should ultimately come into contact with the planet. Now it is interesting to know that Otto Struve, in 1851, arrived at the identical conclusion that "the inner edge of the Saturnian ring was gradually approaching the planet, the whole ring spreading inward, and making the central opening smaller." This conclusion was based on the descriptions and drawings of astronomers of the seventeenth century, and especially of Huygens.*

* Struve, however, has lately reported the results of new measurements made in 1882, from which it appears that the inner diameter of the ring though slightly shorter than in 1851, is less shortened than his theory requires. The space, however, which in 1851 separated the inner or dark ring from the bright one is now closed up, and the dark ring seems to be merely a faint continuation of the bright ring.—*Astron. Nachrichten*, No. 2948. On these rings I cite further, G. A. Hirn: *Mémoire sur les conditions d'équilibre et sur la nature probable des anneaux de Saturn*, 1872; and *Le Monde de Saturn, ses conditions d'existence et de durée*, 1872.

If the "zodiacal light," as commonly supposed, is caused by sunlight reflected from an assemblage consisting of myriads of solid masses of matter, then a similar action must take place among them, and the assemblage must gradually spread itself in the plane of its orbit toward the sun. These interactions would thus conspire with the actions of other interplanetary matter in supplying a continuous descent of meteoroidal substances upon the body of the sun.

If the asteroidal group is, as some suppose, sufficiently numerous to create the probability of frequent collisions, then the slow extension of this group sunward over the plane of the mean orbit is a contingency not to be overlooked.

§ 5. GENERAL REFRIGERATION.

1. *Planetary Refrigeration.*—This is also one of the eventualities of a planet's lifetime, and one which has again and again been brought before our attention. We see this state exemplified in the condition of our satellite, and we believe it has been attained in the satellites of other planets, and even the older of the planets themselves. We have traced the slow processes of planetary desiccation and atmospheric absorption in those planets which belong to the earth group, and have discovered the cause of the perpetual presence of watery vapor and an atmosphere in other planets probably long since frozen to the core. We recognize the refrigerated state as an ulterior stage in all planetary life.

2. *Solar Refrigeration.*—But it may not be fully appreciated that, as the bodies now planets were once suns, so the bodies now suns are destined to be planets. Even the long-enduring sun of our system is destined to be exhausted. I entertain the opinion that most of the heat by which the sun now maintains the activities of his em-

pire is a portion of the primordial heat evolved in the original aggregation of nebular masses and their progressive condensation. Much heat, undoubtedly, has been evolved by later contraction during the periods of planetary history. This process has greatly retarded the lowering of the solar temperature. But the sun has always been cooling, and the reason why his temperature is still so high is simply the vastness of his mass. Whatever accessions of heat may arise from further contraction, or from meteoric or planetary precipitations, will serve only to eke out the original supply. These are indeed necessary inferences from the cosmic theory set forth in the present volume ; but they are also conclusions from independent considerations. Let us glance at some of the data.

(1.) *Inductive Evidences of Secular Lowering of Terrestrial and Solar Temperatures.*—(*a*) In Historic Times. —Very much discussion has taken place on the question whether human observations have established any changes in the mean temperature of terrestrial climates. It is not necessary here to cite the various facts and opinions, but it is important to reproduce the conclusion reached by Professor J. D. Whitney, who has given the whole subject a thorough and patient examination.* He says: "There is evidence very considerable in amount and importance, to the effect that a decrease in temperature during historic times has manifested itself in various ways besides desiccation."

(*b*) In Prehistoric Times—No aspect of the palæontological relics of former periods is less questionable than their testimony to the secular abatement of terrestrial temperature. It is not necessary here to make particular citations of facts, since they are recorded in all manuals

*J. D. Whitney: *The Climatic Changes of Later Geological Times*, 4to., 394 pp., especially 219–41. From the Memoirs of the Museum of Comparative Zoölogy, Cambridge, Vol. vii. See, also, C. König, *Kosmos*, viii, 283-91.

of geological science. The plants, especially, which clothed the lands of the temperate and arctic zones in earlier times, find their modern allies in forms restricted to warmer climates and to lower latitudes than their prototypes.* The evidences, also, of a persistent process of desiccation of the continents during Post-Tertiary time, so industriously accumulated by Professor Whitney,† strongly sustain the inference based on the history of organic life.

(*c*) Cause of Secular Deterioration of Climates.— This conclusion being admitted, the most probable explanation might seem to be the progressive cooling of the earth. This is the explanation generally offered by geologists. There must, assuredly, have been an age when the surface temperature of our planet was largely influenced by the excessive heat of the interior. It is not easy to doubt that this influence must have been experienced to some extent, during the earlier periods of organic life. Still, the present influence of the interior is practically *nil;* and investigation shows that a crust of very moderate thickness would not transmit sufficient warmth to affect the surface to any important extent. "Ten, twenty, thirty times the present rate of augmentation downward," says Sir William Thomson,‡ "could not raise the surface temperature of the earth, and air in contact with it, by more than a small fraction of a degree Fahrenheit. The earth might be a globe of white-hot iron covered with a crust of rock 2,000 feet, or there might be an ice-cold temperature within thirty feet of the surface, yet the climate could not, on that account, be sensibly different from what it is, or the soil be sensibly more or less genial than it is for the roots of trees or smaller plants."§

* Whitney, *op. cit.*, 243–57. † Whitney, *op. cit.*, 121–204.

‡ W. Thomson, *Trans. Geol. Soc., Glasgow*, v. 250.

§ In connection with this we are reminded of the summer vegetation of northern Siberia and sub-arctic America, growing luxuriantly upon a soil underlaid, at the depth of a few inches, by a permanent stratum of ice or frozen earth.

M. Rey de Morande, also, has recently recorded the opinion that "the great uniformity of terrestrial vegetation till the Cenomanian epoch, and gradual differentiation since, according to latitude, the gradual invasion of southern regions by trees with deciduous leaves, and disappearance of all vegetation in polar regions are phenomena" not only testifying to changes in terrestrial climates, but "explicable only by gradual diminution of solar heat."*

We are constrained, therefore, to ascribe the lowering of terrestrial temperatures to the secular cooling of the sun. No other theory has been found free from fatal objections. Among the attempts made to explain the secular cooling of climates, "the only hypothesis of all hitherto suggested that has received no favor from any professed geologist, is that of a warmer sun—the one hypothesis that is rendered almost infinitely probable by independent physical evidence and mathematical calculation."†

We seem, therefore, to face the impressive fact that human experience is able to testify to some actual abatement of the force of the sun, and that the testimonies of the rocks under our feet affirm and extend the grand conclusion that the sun's remoter history has been a history of cooling, and that, consequently, the future must witness a further diminution of solar light and heat.

(2.) *Deductive Considerations Touching Secular Refrigeration.*—The ultimate refrigeration of the sun and planets is only another expression for the dissipation of the energy of the system. As all the forms of energy in the known universe are mutually convertible, so, also, the

**Nature*, xxvii, 119, Nov. 30, 1882, from proceedings of *Acad. des Sciences*, Nov. 20, 1882.

† Sir W. Thomson, *Trans. Geol. Soc., Glasgow*, v, 250. Compare, also, *id.*, iii, 16, 17. Mr. S. V. Wood maintains that the earth's "glacial period" was caused by a diminution in the heat-emitting powers of the sun.—*Geolog. Mag.*, July, 1882.

tendency of the universe is toward the transmutation of all other forms of energy into heat. The tendency of heat is toward diffusion and equilibrium through the processes of radiation and conduction. In other words, the time is foreshadowed when all parts of the solar system and of the material universe will have attained a uniform thermal condition, and all exchanges of heat will have ceased. And this is the finality to be anticipated after all other forms of energy shall have been transformed into heat. In that eventuality, all the forces of nature will have attained an equilibrated or exhausted condition. No more motion — no more light or electricity, or heat — the last course of physical change will have been complete.

More than twenty-three years ago I was led to the adoption of such views, and recorded them in these words: "All the present motions of the universe, whether physical or physiological, are but the phenomena attendant upon the progression of matter toward a state of ultimate equilibrium. * * * The tendency of all physical forces toward a state of equilibrium and rest will result in a complete equilibrated diffusion of all self-repellant matter, and a concentration into one mass of all self-attractive matter. * * * It is not likely that the material universe is infinite. * * * When light, heat, electricity and other 'imponderable agents' (if any) shall have become uniformly distributed throughout matter, and have thus been brought to a state of equilibrity, both in themselves and in respect to matter, there can not be either sun, star or other radiant source of light and heat, or any of the motions produced by these agents in the organic and inorganic worlds. * * * There must have been a beginning to this series of evolutions."*

* *The Cycles of Matter, or the Permanence of the Earth and the Destiny of the Race*, Michigan Journal of Education, viii, 273-8, Aug., 1860. Compare Spencer's chap. xvi (published in 1862), on "Equilibration," in *First Principles*.

Such deductions, however, had been reached by Professor (now Sir) William Thomson eight years earlier, though information of the fact had not reached the present writer.* His conclusions are as follows: (*a*) "There is at present in the material world, a universal tendency to the dissipation of mechanical energy. (*b*) Any *restoration* of mechanical energy without more than an equivalent dissipation is impossible in inanimate material processes, and is probably never effected by means of organized matter, either endowed with vegetable life or subjected to the will of an animated creature. (*c*) Within a finite period of time past, the earth must have been, and within a finite period of time to come, the earth must again be, unfit for the habitation of man as at present constituted, unless operations have been, or are to be performed, which are impossible under the laws to which the known operations going on at present in the material world are subject."†

According to this doctrine, the heat of our system — chiefly solar — on which all its activities depend, is undergoing a gradual dissipation in infinite space. It is not annihilated, but it is lost to us. In the distant future, all parts of the system will be reduced to the mean temperature of space, and the wheels of the organism will cease to move.

We may anticipate that the cooling sun will pass through phases similar to those of forming planets. A liquid central globe will grow, and, as it enlarges, solidi-

*Professor W. Thomson's Memoir, *On a Universal Tendency to the Dissipation of Mechanical Energy*, was read before the Royal Society of Edinburgh, April 19, 1852, and communicated by the author to the London, Edinburgh and Dublin Philosophical Magazine for publication, October, 1852, Series IV, vol. iv, pp. 304–6.

†See also the celebrated essay of Helmholtz on the *Interaction of Natural Forces*, first presented as a lecture at Königsberg, in 1854 — *Correlation and Conservation of Forces*, Youman's ed., 242–4, etc. Mayer, also, glanced in the same direction, in 1851, but he only raised a query.—*Id.* 355.

fication will appear at the core. It will become incrusted. Its light will grow ruddy and dim. The vapors of water will condense in the sun's atmosphere. A stormy stage of long duration will ensue. Surface waters will accumulate to some extent upon the darkened exterior. We may infer, however, that the relative supply of water will be scant. The pores of the fire-formed rocks will eagerly drink it up. The cooled and planetary surface will emerge from the tumult of the secular storm; but a starlit firmament will overhang it. Its own inherent warmth may, for a secular period, preserve a habitable temperature; but if organic creatures find existence on it, they must possess nocturnal instincts. Later on in the eternities, this sunless planet — this exhausted and planetized sun — will have felt the chill of surrounding space. In the remotest finality which deductive science can reach, the sun and planets will have been gathered in one central mass. All fire and light will have been extinguished. No relative motion will survive — only the dead, cold corse will rotate on an axis and travel onward in its mysterious, endless, aimless course through the eternities still to come.*

Thus, by the telescope of deductive science, we are able to glance "through the corridors of time" to come, and anticipate with assurance the approach of events as remote in the coming direction as those primordial events in the opposite direction which we have seen connected with the cradle of the Solar System. But in so distant a glance all perspective is lost. Like the stars in the firmament, those events are projected upon one common ground. It is impossible to assert in what order these final consummations will be realized. We only know they

* The present writer has reflected much on these eventualities. See, besides the memoir already cited, *The Ladies' Repository*, Cincinnati, Nov. and Dec., 1863, and Jan., 1864; *Sketches of Creation*, 1870, 380–431, and various other publications.

are inclosed in the future. The sun will probably assume a planetary condition only after the last precipitations shall have taken place. The continents may be levelled before the synchronistic stage of the earth and moon is reached. The precipitative tendencies of tidal action may exceed those resulting from resistances encountered in planetary space. Whatever the order of progress toward these planetary issues, and to whatever distance removed, these tendencies are so many categories of change which demonstrate that a terrestrial, and more generally a planetary, and even a cosmical, finality must be reached. The world is finite in duration. The Solar System is finite. The entire cosmical organism is finite in duration. That which is approaching a limit to its existence in one direction has proceeded from finite limits in the opposite direction. There was a time when the cosmical organism began to exist. Even if it was an older framework reorganized, it was a new beginning. Whatever the number of times it had been begun, there was a first time. If there was a first time, then at that moment cosmical existence was *out of the order of causal relations in the natural world.* If there was *not* a first organization, then the cosmic organism is eternal; *it does not run down or wear out; it is out of the order of causal relations in the natural world.*

3. *Revivification of a Dead Universe.*—The ultimate precipitation upon the sun of all the matter in our system would not end the existence of matter or of energy, but only the existence of one department of the cosmic organism. That other systems have already attained this condition can hardly be doubted. Nor is it easier to doubt that in the exhaustless and perhaps unexplored resources of the cosmic economy some means exist for

restoration of an effete system to a renewal of intense cosmical activity.*

Nor would the complete equilibrium of the total energy of the visible universe end the existence of matter or of energy. We must still believe in an appointed reëxcitation of the slumbering potencies of the cosmic elements. By what natural means this could be effected, we cannot even surmise.

A suggestion toward a possible means for this end was made by Rankine in 1852, soon after the appearance of Thomson's memoir.† He holds that the interstellar medium must be perfectly transparent and diathermanous, and thus "incapable of acquiring any temperature whatever, and all heat which arrives in the conductible form at the limits of the atmosphere of a star or planet will there be totally converted, partly into ordinary motion by the expansion of the atmosphere, and partly into the radiant form. The ordinary motion will again be converted into radiant heat, so that *radiant* heat is the ultimate form to which all physical energy tends. * * * Let it now be supposed that in all directions round the visible world the interstellar medium has bounds, beyond which there is empty space. Then, on reaching those bounds, the radiant heat of the world will be totally reflected, and will ultimately be concentrated into foci. At each of these foci the intensity of heat may be expected to be such that should a star (being at this period an extinct mass of inert compounds) in the course of its motions arrive at that part of space, it will be vaporized and resolved into

* Spencer: *First Principles*, Am, ed., 480. So Kant: Kann man nicht glauben, die Natur, welche vermögend war, sich aus dem Chaos in eine regelmässige Ordnung und in ein geschicktes System zu setzen, sei ebenfalls im Stande aus dem nenen Chaos, darin sie die Verminderung ihrer Bewegungen versenkt hat, sich wiederum eben so leicht herzustellen, und die erste Verbindung zu erneuern?—KANT, *Werke*, Hartenstein ed., i, 302.

† W. J. M. Rankine: *On the Reconcentration of the Mechanical Energy of the Universe*, Phil. Mag., IV, iv, 358–60, Nov., 1852.

elements. * * * These opposite processes may go on together. Some of the luminous objects which we see in distant regions of space may be not stars, but foci in the interstellar ether."

The improbability of this curious conception impresses itself at once. The limitation of the ethereal vehicle of starry radiations is not easy to grant, though thinkable. The luminiferous medium is not perfectly transparent and diathermanous. The mode of action by which the radiations are returned is too mysterious to make part of a hypothesis. The concentration of the rays is equally mysterious. The existence of moving bodies is incompatible with the premise of a full equilibrium of cosmic forces. And finally, if all these doubts could be removed, the intense focal heat contemplated would be an impossibility.

The last point has been fully demonstrated by Clausius.* He proves that it contravenes the second law of thermodynamics, which declares that "it is impossible by the unaided action of natural processes, to transform any part of the heat of a body into mechanical work, except by allowing heat to pass from that body into one of a lower temperature." † Clausius has simplified the expression of this law in a way which suits the present case, by stating it thus: "*Heat cannot pass of itself, i. e., without compensation, from a colder to a warmer body.*" Now the conception of Rankine requires that radiations of energy shall be concentrated through reflection, in such a way that a body placed at a focal point shall become heated to a higher temperature than the bodies possess from which the radiations proceeded. Clausius, on the

* R. Clausius: *Ueber die Concentration von Wärme und Lichtstrahlen und die Gränzen ihrer Wirkung*, Pogg. Annal., cxxi, 1-44, 1864, read at the Zürich Natural History Society, June 22, 1863; more fully elaborated in *Die Mechanische Wärmetheorie*, 2d ed., i, 315-53.

† Maxwell: *Theory of Heat*, 153; Clausius: *Die Mechanische Wärmetheorie*. i, 72, 81, 82.

contrary, proves (1) "That the force of emission of a body depends not alone on its constitution, but also on the nature of the surrounding medium, in such a way that the force of emission in different media is inversely as the square of the velocity of propagation of the rays in the medium, or directly as the square of the coefficient of refraction of the medium," and (2) "That the second law of thermodynamics is valid not only in cases where no concentration takes place, but equally in cases where it takes place." It follows that no such method of reconcentration of cosmical energy as Rankine suggested is compatible with the established processes of nature. Nor is science able, at present, to point out any natural means by which the dissipation of energy from our system may be arrested, or the impending equilibrium of energy throughout the universe, again disturbed.

Nevertheless, there remains to us an abiding conviction, as expressed by Kant in the middle of the last century, and which Mr. Spencer bases on *a priori* grounds, that the activities of a dead universe may be renewed. "Motion," he says, "as well as matter, being fixed in quantity, it would seem that the change in the distribution of Matter which Motion effects, coming to a limit in whichever direction it is carried, the indestructible Motion thereupon necessitates a reverse distribution. Apparently, the universally coexistent forces of attraction and repulsion, which, as we have seen, necessitate rhythm in all minor changes throughout the Universe, also necessitate rhythm in the totality of its changes — produce now an immeasurable period during which the attractive forces predominating cause universal concentration, and then an immeasurable period, during which the repulsive forces predominating cause universal diffusion — alternate eras of Evolution and Dissolution." * These recurrences of

* Spencer: *First Principles*, 482.

cosmical activity and rest were traced in my essay of 1860, and designated "The Cycles of Matter."

The reorganization of a Universe in which the series of events has reached the last term attainable by action according to known laws, presents before us a problem of the same order as that of the origination of matter and energy. It may not be necessary to despair of the discovery of the natural means of recuperation of worn-out systems; but, as long as the means remain undiscovered, it is philosophically legitimate to contemplate a restitution by the intervention of such power as was exercised in the first institution of cosmical order, and in the origination of the matter, the efficiency and the method revealed in the living cosmos.

CHAPTER V.

HABITABILITY OF OTHER WORLDS.

Da wir durch die spectralanalyse wissen, dass die chemischen Elemente, aus den Planeten und Fixsterne bestehen, nicht *toto genere* von den auf der Erde anzutreffenden verschieden sind, so werden wir auch bezüglich der organischen Entwickelungen auf den Planeten ähnliche Wirkung schliessen dürfen. —ZÖLLNER.

Toutes les vérités mathématiques doivent être les mêmes dans l'étoile *Sirius* et dans notre petite loge.— VOLTAIRE.

L'homme fait pour la température dont il jouit sur la terre, ne pourrait pas, selon toute apparence, vivre sur les autres planètes; mais ne doit-il pas y avoir une infinité d'organisations relatives aux diverses températures des globes de cet univers ?—LAPLACE.

If the reader should have a mind to amuse himself with probable guesses about the furniture of the planets of our solar system, what countries 'tis probable are there, what vegetables are produced, what minerals and metals are afforded, what animals live there, what parts, faculties and endowments they have, with much more to the same purpose, he may find a pleasant entertainment in the great Mr. Christian Huygens' Cosmotheoros, and some other authors that have written on the subject.— WILLIAM DERHAM, 1714.

§1. SOME REFERENCES TO LITERATURE ON THE SUBJECT.

THE habitability of other worlds is a question on which a vast amount of speculation has been expended. It has been the general belief that many other worlds are inhabited.* Dr. Lardner argued the habitability of the

*Giordano Bruno: *De l'Infinito Universo e Mondi Innumerabili*, 1584; Christian Huygens: *Cosmotheoros, sive de Terris Cœlestibus, earumque ornatu conjecturæ*, Huygenii Opera, tom. ii, 645-722, Eng. translation, *The Celestial Worlds Discovered, or Conjectures concerning the Inhabitants, Plants and Productions of the Worlds in the Planets*, 1698, 2d ed. 1722; William Derham: *Astrotheology*, 1714, 3d ed. 1717, pp. xlvii, liii, liv, 9th ed. 1750, pp. xxx, xxxiv, xxxv: Immanuel Kant: *Allgemeine Naturgeschichte*, etc., 1755, 3ter. Theil, Sämmtliche Werke, i, 329-45; Laplace: *Système du Monde*, 5th ed., 1824, 389; Fontenelle: *Dialogues on the Plurality of Worlds*, 1686, 2d ed. 1719; Sir David Brewster: *More Worlds than One;* C. Flammarion: *La Pluralité des Mondes Habités*,

moon and all the planets.* Dr. Brewster held similar views. Some have even maintained that the physical condition of the body of the sun may be such as to produce a state of habitability. † Sir William Herschel is said to have conjectured that the solar spots are the highest points — some 600 miles high — of a cool and habitable globe. ‡

On the contrary, the habitability of other worlds has been denied on theological grounds. § It was formerly a common theological belief that the biblical teaching is incompatible with the doctrine of other worlds of beings. Dr. Whewell disputed the plurality of worlds by appeal to scientific evidence. ‖

§ 2. THE HUMAN STANDARD OF HABITABILITY NOT ABSOLUTE.

The question of the habitability of other worlds has generally been discussed from the assumption that all other corporeal beings must be clothed in flesh and bones similar to those of terrestrial animals, and must be adapted to a similar physical environment. But it is manifest, on a moment's consideration, that corporeality may exist under very divergent conditions. It is not at all improbable that substances of a refractory nature might be so mixed with other substances, known or unknown to us, as to be capable

8vo., 1864; R. A. Proctor: *Other Worlds than Ours;* C. Du Prel: *Die Planetenbewohner und die Nebularhypothese, Neue Studien zur Entwickelungsgeschichte des Weltalls*, gr. 8°, Leipzig, 1880; Bentley: *Boyle Lectures*, Lect. viii, ed. 1724, p. 298, seq.; W. Miller: *The Heavenly Bodies, their Nature and Habitability*, 344 pp., London, 1883.

* Lardner: *Museum of Science and Art.*

† President Forbes: *Reflections on the Sources of Incredulity with regard to Religion*, Edinb. 1750, p. 3; Dr. Elliot, *Edinb. Encyc.*, Art. Astronomy, vol. ii, 616; *Gentlemen's Magazine*, 1787, 636. Compare also the works of Flammarion, Jean Reynaud, Babinet and Pioger.

‡ I have not yet found this opinion recorded in his writings.

§ Maxwell: *Plurality of Worlds*, 1823). He holds that the Newtonian philosophy contains principles "which lie at the foundation of all atheistical systems."

‖ Whewell: *Of the Plurality of Worlds.*

of enduring vastly greater vicissitudes of heat and cold than is possible with terrestrial organisms.* The tissues of terrestrial animals are simply suited to terrestrial conditions. Yet even here we find different types and species of animals adapted to the trials of extremely dissimilar situations.

Nor is it to be supposed that the plans of structure of animals on other habitable planets bear necessarily any analogy to organic plans on the earth. That an animal should be a quadruped or a biped is something not depending on the necessities of organization, or instinct, or intelligence. That an animal should possess just five senses is not a necessity of percipient existence. There may be animals on the earth which neither smell nor taste. There may be beings on other worlds, and even on this, who possess more numerous senses than we. The possibility of this is apparent when we consider the high probability that other properties and other modes of existence lie among the resources of the cosmos, and even of terrestrial matter.

There are animals which subsist where rational man would perish — in the soil, in the river and the sea. No reason can be assigned why aquatic respiration should be confined to brute animals. On a planet without land, like Uranus, high intelligence might be enframed in a gill-bearing embodiment; and resources and stimuli for intellectual activity might be discovered in the bottom of the ocean, or in the infinitesimal world which fills a slimy pool, or "swarms upon the thickly peopled air." Nor is incorporated rational existence conditioned on warm blood, nor on any temperature which does not change the forms of matter of which the organism may be composed. There may be intelligences corporealized after some concept not

* While these pages are in the printer's hands, similar suggestions appear from others. See Charles Morris, *Amer. Naturalist*, xvii, 930-1, Sept., 1883, and E. D. Cope, *Science*, ii, 279, Aug. 31, 1883, in an address at Minneapolis.

involving the processes of injestion, assimilation and reproduction. Such bodies would not require daily food and warmth. They might be lost in the abysses of the ocean, or laid up on a stormy cliff through the tempests of an arctic winter, or plunged in a volcano for a hundred years, and yet retain consciousness and thought. It is conceivable. Why might not psychic natures be enshrined in indestructible flint and platinum? These substances are no further from the nature of intelligence than carbon, hydrogen, oxygen and lime. But, not to carry the thought to such an extreme, might not high intelligence be embodied in frames as indifferent to external conditions as the sage of the western plains or the lichens of Labrador—the rotifers which remain dried for years or the bacteria which pass living through boiling water. Again, there is no reason why a given amount of light should accompany intelligent organization. Many animals, not among the least intelligent, find the night their appropriate period of activity. Some exist and thrive in rayless caverns and ocean depths. On a planet dimly lighted, like Neptune, men might be organized with pupils as large as silver dollars, or even as large as dinner plates. Vision might be as distinct on Neptune as on the earth. As to warmth, a blanket of vapors may keep it in and accumulate it to the requisite extent. And in that distant time when the sun shall become planetary, large-orbed men may move about in star light over a surface sufficiently warmed by internal heat, and forms of vegetation may flourish, and supply food for man and beast without the stimulus of solar radiations. These suggestions are made simply to remind the reader how little can be argued respecting the necessary conditions of intelligent, organized existence, from the standard of corporeal existence found upon the earth. Intelligence is, from its nature, as universal and as uniform as the laws of the universe. Bodies are merely the local

fitting of intelligence to particular modifications of universal matter and force.

§ 3. HABITABILITY UNDER THE HUMAN STANDARD.

But let us consider how far other worlds are suited for habitations for beings akin to ourselves. This is a question for scientific consideration. The answer to the question, when asked with reference to each of our planets, is to be sought in what has been already said concerning the physical conditions of the planets. Mercury is not habitable for beings like ourselves. Proximity to the sun results in a destructive degree of heat, if it does not actually prevent all water from finding a resting place on the planet's surface. The sun's apparent diameter from Mercury is more than two and a half times as great as from the earth.

In reference to Venus, and possibly also Mercury, we must bear in mind that the relations of heat and water are such that water might exist as a dense and permanent envelope of clouds. This seems the more probable, even for Mercury, in view of Professor Langley's determination of the astonishing rate of radiation in a thin atmosphere. At the upper limit of an atmosphere sufficiently dense to support aqueous vapor, it seems not irrational to assume that escape of heat would be rapid enough to condense water even in the fierce solar heat experienced at Mercury's distance from the sun. So far as the existence of a stratum of clouds is possible, this would, of course, serve as a screen for the surface of the planet, so that comparatively little of the sun's direct radiation would interfere with habitability. In this view there seems no great improbability that both these planets are inhabited by intelligences organized somewhat like ourselves. The amount of water belonging to these planets being in less proportion than on the earth, the processes of evaporation and

precipitation must keep it in active circulation. No very considerable bodies of water can be supposed to exist, and a large proportion of the entire surface must be accessible to occupation and cultivation. The final absorption of the water will, therefore, occur at a relatively early epoch, when, of course, habitability must end.

Thus, the first thought of these sister worlds suggests that they may be the homes of beings kindred to ourselves. Then the knowledge of the intensity of the solar radiations on their surfaces seems to preclude the belief in their habitability. But finally, a discovery of natural means for the alleviation of excessive heat leaves us with the conviction that after all we may have neighbors on the contiguous planetary territory. As to their organization, while it is profoundly true that under circumstances extremely diverse from those under which we live, extremely diverse organizations must be conceived both possible and probable; yet where the divergence is no greater than on the interior planets, all the fundamental functions and processes may be conceived analogous to our own. There is so widespread uniformity in the nature and action of physical forces that we may suspect the same in regard to organic structures and activities. As organization in its forms and functions is conditioned by the properties of matter and the laws of energy, and these conditions are widely pervasive throughout our system, we have good ground for believing that plans of organization and modes of activity are fundamentally analogous under all planetary conditions not more diverse than we conceive those of the earth and the interior planets to be. In fact, there exist contrasts of condition upon the earth nearly as wide as the contrasts between the earth and Venus. In all these contrasted situations nature employs the same fundamental plans of organization and functioning.

On the whole, as intelligence must be revealed in the cosmic organization of Mercury and Venus, there are presumably intelligent beings in correlation with the intelligible world; and as the conditions of corporeality are so far analogous to those on the earth, we may reasonably conceive organic intelligences on those planets who have power of locomotion by muscles and bones; who eat and respire; who suffer and enjoy; who cognize light and heat and sound; who observe and reflect, imagine and aspire; and, while ignorant, probably, of many or most of our arts, have invented many others of which we never dreamed, and achieve accomplishments which would be miracles to us.

The moon, in the absence of air and water, must be without inhabitants akin to ourselves. Though the moon has passed through the successive phases of a cooling globe, I cannot think the violence which must have reigned on its surface before synchronistic times would have permitted the existence of an organic being. Nor, since the synchronistic period began, have the conditions, as far as we can judge, been endurable. The fortnightly alternations of extreme heat and extreme cold must prove fatal to all organic life with which we are acquainted. It is pleasant to think of kindred beings on a neighboring world, though we might not by any possibility open intercourse with them. It is pleasant even to believe that the moon may have been inhabited in a former planetary period. It creates a sense of relation to distant parts of the universe to believe that other beings may even have lived there and passed away. To know that the lunar surface is a wild scene of desolation, and to know that only the unconscious forces of inorganic nature have ever interrupted the oppressive silence of the planetary solitude, seems to sunder a bond of sympathy with the universe, and isolate mankind on an island rock where no

message can ever arrive. But it is better to know the truth than to indulge in fancy. The moon is probably no more uninhabitable in the present period than it has been during its entire history.*

Mars, according to the scientific indications, presents conditions more nearly approximating the demands of habitability than any other planet besides the earth. It seems almost certain, however, that the meridian of its habitable phase is passed. The sun's apparent diameter from Mars is two-thirds his size seen from the earth, and his light and heat are only three-eighths as much as the earth receives. As the intensity of gravity on the surface of Mars is only three-eighths the intensity of gravity on the earth, many diverse conditions would be introduced. A man of ordinary agility would be able to leap over a wall twelve feet high. If on the earth, a strong man is able to support 26 pounds in his palm at arm's length, and his arm is equivalent to four pounds in his palm, he might be 42½ feet high before the weight of his arm would become too great for him to extend it; but on the planet Mars, such a man might be 109 feet in height.† Again, considering

*In my brochure, entitled *Geology of the Stars*, speaking of the comparatively rapid succession of lunar periods, I said: "The zoic age of the moon was reached while yet our world remained, perhaps, in a glowing condition. Its human period was passing while the *Eozoön* was solitary occupant of our primeval ocean." Mr. Fisk, in his *Cosmic Philosophy* (i, 400, note), has cited this as "an example of the too hasty kind of inference which is often drawn in discussing the question of life upon other planets." Mr. Fisk misapprehends, for it is not stated that human beings ever lived, or could have lived, upon the moon. The allusion is simply to that stage of lunar evolution which corresponded to the human stage in terrestrial evolution.

†If w = the total weight a strong man's arm can support, including weight of arm and load, and p = weight of arm, and n equal number of times greater, in any dimension, the arm is which could bear no load, then $n = \frac{w}{p}$ (Young's *Mechanics*, Williams' ed., p. 113), and if g' = gravity on any planet compared with gravity on the earth, then, on that planet

$$n = \frac{w}{p\,g'}.$$

Now, if we assume that a man can raise 26 pounds at arm's length, and that his arm is equal to 4 pounds in his palm, then $n = 7.5$; and if a strong man's

that the Martial atmosphere is likely to be .105 that of the earth, and is spread over .2828 the same amount of surface, its density on the surface of the planet is only .1379 that of the earth's surface atmosphere, giving a pressure on the mercurial barometer of about 4.14 inches. The height of the Martial atmosphere reduced to uniform surface density would be 2.694 times that of the earth's atmosphere, or about 13.56 miles. The surface density of the Martial atmosphere is only such as would be attained on the earth at the height of 10.2 miles.* This implies a universal state of atmospheric tenuity on the surface of Mars which has not been found compatible with any terrestrial life. The simple difference in mass creates conditions which would render the surface of Mars completely untenable by any human being; and this consideration, it might have been stated, applies as well to Mercury and the Moon. But this is no proof that organic beings suited to such atmospheric pressure do not exist. Animals are dredged from oceanic depths where the pressure as much exceeds the sea level pressure as the atmospheric density of Mars falls below the terrestrial standard. Animals are adapted as they are because the conditions are as they are; and we may feel assured that if the conditions were different, organic adaptations would be different correspondingly. The conceivable range of adapta-

height is 68 inches, the height of a man on the earth who could barely extend his arm — since his height is proportional to his arm's length — would be 68 inches $\times$ 7.5 = 42.5 feet; and the height of such a man on Mars would be $\frac{42.5}{.391} = 108.95$ feet.

* If h = the height at which the density of the earth's atmosphere is $\frac{1}{n}$ that at sea level, then, since the density diminishes in a geometrical ratio as the height increases in an arithmetical ratio, the height $2h$ will give a density of $\frac{1}{n^2}$; the height $3h$ will give a density of $\frac{1}{n^3}$; and generally the height xh will give a density of $\frac{1}{n^x}$. But $\frac{1}{n^x} = .1379$, whence, if $n = 2$ and $h = 2.705$ miles, $x = 3.77$ and $xh = 3.77 \times 2.705 = 10.2$ miles.

tions is limited only by the physical properties of inorganic matter.

On the planet Jupiter, the mass so much exceeds that of the earth that all the relative conditions are reversed. I have shown that atmospheric density is nearly $6\frac{1}{2}$ times as great as on the earth. Hence respiration would only need to be $6\frac{1}{2}$ times less active. On the contrary, the force required to sustain the body against gravity would be more than $2\frac{1}{2}$ times as great, and all weights would be $2\frac{1}{2}$ times as difficult to move. This increased weight of the body and limbs would render comparatively less efficient similar muscular efforts, while the gravitational resistances to be overcome would be greater. A man $16\frac{1}{4}$ feet high would be barely able to extend his arm at a right angle with his body. If ever the planet Jupiter attains a habitable condition its organic beings will be limited in some such manner as these numerical results imply.

The apparent diameter of the sun from Jupiter is only .2392 or $\frac{1}{4\cdot 2}$ the same from the earth; and the sun's radiant energies in the forms of light, heat, actinism and attraction, are only $\frac{1}{27}$ of the same at the earth. Were the sun's heat reduced on the earth to $\frac{1}{27}$ its present amount, it is manifest that all organic life must perish. If ever, therefore, the inherent temperature of Jupiter subsides so far as to bring his surface condition to that of the earth, no Jovian climate will be such as animal organization can endure. As his actual surface temperature, however, will always be compounded of the effects of solar radiation and of conduction from within, there will be an epoch when his actual mean surface temperature will be the same as the earth's actual mean surface temperature. The vicissitudes of the seasons will be $\frac{1}{27}$ as great as on the earth — regardless of the effect of less obliquity of the axis — and the diurnal and nocturnal fluctuations of temperature will be only $\frac{1}{27}$ as great. Owing to a denser at-

mosphere, the fluctuations will be even less than this. The higher inherent temperature of the soil will result in so much radiation from the planet that on a planet with so large a supply of water, and in an atmosphere so dense as Jupiter's the sun's deficient heat may be largely compensated by suppressed radiation from the planet. The situation will be that of a mild and dimly lighted "stove" in horticultural operations, highly suitable for the growth of mushrooms. It will be perpetual evening. It can not be doubted that corporeal intelligences might be coördinated to such a physical condition. For the present, however, we have not the slightest grounds for imagining the existence of organic populations upon the surface of Jupiter, unless they depart in some very extreme way from the terrestrial standard.

As to the planets remoter from the sun, I have offered reasons for considering them advanced to a state of total refrigeration. They cannot therefore, be conceived as habitable. There was a time, however, in the history of each, when its stage of cooling produced a surface temperature suited for organic life. At that stage, the relations of organic beings on their surfaces were similar to those which may be anticipated for Jupiter, with all the greater divergences from the terrestrial condition which depend on distance from the sun carried to successively greater extremes, and successively larger proportions of water and gaseous substances. On Neptune the apparent diameter of the sun is but $\frac{1}{4}\frac{1}{0}$ the sun's apparent diameter to us, and his heat and light are reduced to $\frac{1}{9}\frac{1}{0}\frac{1}{0}$ the heat and light received by the earth. This light would, nevertheless, be equal to about 69 of our moons. The excess of water however, on all the distant planets, in accordance with views heretofore presented, would probably render them, in all stages of existence, totally uninhabitable for beings like ourselves. But it is always to be re-

membered that other beings suited to the actual exigences of the environment, may have occupied the situation.

The earth, then, so far as we can reason, is in the middle of the habitable zone of the solar system, if our own natures are assumed as the criterion of habitability. On either side, the rigor of the physical conditions seems to proclaim our system a voiceless and lifeless desert. Even our near neighbor, the moon, lies on the borders of this desert. Within the vast limits of the solar system there is but one happy niche where corporeal organization according to our standard can enter into material relations with the physical environment. The conclusion is undoubtedly disappointing. But the impression is further deepened by the reflection that on our own congenial planet life is hemmed in between the terrestrial surface and the upper limit of a film of atmosphere not thicker than the mean depth of the film of ocean which enwraps the solid globe. The entire human family swarms within a sheet of atmosphere not over three miles thick. Above, are the rigors of unendurable cold, and the horrors of unsupported respiration. Below, are the impenetrable rocks or the submerging waves or the internal fires. Even the space about us and nearest to us is, for the greater part, inaccessible to man, and unvisited by any organic being. We need not wonder that corporeal existence is a rarity through all the realm of our system.

But there are other suns and other planetary systems, and other worlds which possess the conditions of habitability. When we look on the hosts of stars, and consider that if only one habitable planet wanders about each sun, we understand that the number of habitable worlds is countless. In this view, space seems to be densely populated. We have neighbors; they live beyond impassable barriers, but they gaze on the same galaxy, and we know they are endowed with certain faculties which

establish a community between them and us. However conformed bodily, whatever their modes and means of organic activity, we know that they reason as we reason, and interpret the universe on the same principles of logic and mathematics as ourselves. The orbits which their planetary homes describe are ellipses; they have studied the same celestial geometry as ourselves; they have written their treatises on celestial mechanics; they have felt the impact of the luminous wave of ether; they have speculated on the nature of matter and energy; they have interpreted the order of the cosmical mechanism as the expression of thought and purpose; they have placed themselves in communion with the Supreme Thinker, who is so near to all of us that his voice is audible alike to the ear of reason in all the worlds.

PART III.

GENERAL COSMOGONY.

Das All einem jener südlichen Bäume gleicht an denen zu denselben Zeit, hier eine Blüthe aufgeht, dort eine Frucht von Zweige fällt.—STRAUSS.

Auf gleiche Weise verlassen ganze Welten und Systeme den Schauplatz, nachdem sie ihre Rolle ausgespielt haben. * * * Indessen, dass die Natur mit veränderlichen Auftritten die Ewigkeit ausziert, bleibt Gott in einer unaufhörlichen Schöpfung geschäftig, den Zeug zur Bildung noch grösserer Welten zu formen.—KANT.

Mit welcher Art der Ehrfurcht muss nicht die Seele sogar ihr eigen Wesen ansehen, wenn sie betrachtet, dass sie noch alle diese Veränderungen überleben soll.—KANT.

CHAPTER I.

FIXED STARS AND NEBULÆ.

§ 1. CONDITIONS OF THE FIXED STARS.

1. *Double, Triple and Multiple Stars.*

THAT some of the fixed stars are the result of the gradual condensation of nebulous matter about a centre was the conjecture of Sir William Herschel. I believe that the stars in general have resulted from nebular condensation; but in many cases — probably not in all — a rotation has arisen whose influence has been permamanently impressed on the course of events. The condition of our own system, and the history deduced from it, make known a natural and probable mode of evolution of other systems; and it cannot reasonably be denied that many other systems have come into existence in a similar way. Other planets, consequently, revolve in nearly circular orbits about many other suns. It is not impossible, however, that a non-rotating sun should be attended by planets which have not been disengaged from its own mass. It is, indeed, probable, that many small cosmical bodies should have been thrown by contending attractions into paths which pass near great centres of attraction. While many of these must have moved with velocities which would carry them on in hyperbolic curves, others may have moved with velocities so low as to pass into elliptic orbits, and thus become planets or satellites to greater bodies. The comets of our own system seem to realize both these conjectures. But a planetary relation established in this manner would present an orbit of

high eccentricity. Moreover, it seems probable, considering the immensity of the intervals of space, and the great distance from which a smaller mass would approach a greater, that in nearly all cases a velocity would be acquired too great for the assumption of elliptic orbits. This would be especially the case with approaching bodies having sufficient mass to constitute a planet. More insignificant collections of matter would be more under the control of central masses. Hence foreign bodies introduced into a system would be more probably of a cometary than of a planetary character.

That other suns are attended by planets is a fact of observation; though no planetary attendant would be visible except such as retain still an incandescent character. Hundreds and even thousands of stars have been pronounced "double;" and, in a number of cases, the two components have been observed in a process of revolution about the common centre of gravity.* Not less than fifteen of these have been observed sufficiently long to determine their periods of revolution; and several have been actually traced through complete revolutions.†

It needs hardly be said that no attendant of a sun would be visible unless itself of very great magnitude, and hence having sufficient mass to compel a visible amount of motion in its nominal central body. How many smaller, and therefore, invisible, planets though still luminous, and how many smaller and darkened planets, may revolve about the same centre, is matter open to conjecture; but

* Struve, in *Mensuræ Micrometricæ*, Dorpat, 1837, enumerated 3,000 double stars, most of which had been noted by Sir William Herschel. To this number Otto Struvé of Pulkova has added 500; and Mr. S. W. Burnham announces that he has detected 900 new pairs. Others have reported perhaps 50 new discoveries. This makes an aggregate of 4,450 double stars.

† Zeta, of Hercules, has a period of 36 years; Eta, of the Northern Crown, a period of 43 years; Zeta, of the Crab, 59 years; Xi, of the Great Bear, 63 years. Others have still longer periods — one in Virgo being 513 years, and that of Gamma, of the Lion, 1,200 years,

I believe we may fairly assume that such planetary attendants must be exceedingly numerous. It seems a natural conjecture that all these luminous attendants of other stars are planetary or derived bodies in the same condition as once characterized the earth, and more recently, perhaps, the largest planet of our system. "These planets," says Secchi, "differ from ours only in a single point, they are still incandescent, and consequently self-luminous."

What is more remarkable and interesting is the fact that many stars appear triple and multiple. Mr. S. W. Burnham publishes a list of 53 stars enumerated in Struve's catalogue, in which a "closer component" has been more recently discovered — the majority of them by himself.* These are then so many cases of stars associated in groups as high as triplets. But among them are instances in which a fourth, fifth, sixth and seventh component has been detected. Theta of Orion is a celebrated septuple star. The first inference which one feels tempted to draw from the phenomena of triple and multiple stars is the existence in one system, of more than one planet retaining a self-luminous condition. It might be suggested, however, that even satellites of still luminous planets may retain the luminous condition. In this case we should ultimately detect orbital motion around one of the components, together with motion around the common centre of gravity of the system. This is an interesting inquiry for astronomy.†

2. *Temporary Stars.*—From time to time during centuries past, stars have been seen to burst forth into luminosity in situations before unoccupied, increase in bril-

*S. W. Burnham, *Science*, ii, 35, January 22, 1881.

†It is quite possible that two stars under the combined influence of mutual attraction and antecedent motion, not approaching sufficiently near for coalescence, should enter upon orbital revolutions about their common centre of gravity.

liancy for a few weeks or months, and then gradually wane, changing from white to yellow and red, and finally disappearing. According to Humboldt, twenty-one such stars were recorded during the interval of 2,000 years between 134 B.C. and 1848 A.D. The most remarkable of these occured in 1572 in Cassiopœia, and was specially studied by Tycho Brahe. It exceeded in brilliancy both Sirius and Jupiter. Another remarkable occurrence took place in 1604, in Ophiucus, and was studied by Kepler. This star nearly equalled Venus in brightness, but at the end of fifteen months was so diminished as to be merely a telescopic object. Another was discovered by Hind, in 1848. The one which occurred in May, 1866, in the Northern Crown, exceeded the second magnitude in brightness.

The last mentioned was spectroscopically investigated. According to Huggins, the spectrum indicated two distinct sources of light, each producing a separate spectrum. One was a continuous spectrum crossed by dark lines, similar to that yielded by the sun and most of the stars. The other consisted of four brilliantly bright lines. The first spectrum showed a photosphere of incandescent matter either solid or liquid, surrounded by an atmosphere of cooler vapors giving rise by absorption to the dark lines. The other spectrum showed the presence of an intensely luminous gas which, according to Huggins, was apparently hydrogen at a higher temperature than existed in the photosphere of the star. These spectral phenomena have prompted the suggestion by Huggins, and separately by Rayet and Wolf, that the sudden brightness of the star was caused by an outburst of intensely heated hydrogen gas, which, by gradual exhaustion, occasioned the waning brilliancy of the star. Others have attributed it to collision with some other orb; but this idea is set aside by the rapidity of the decrease in brilliancy, as well as by the supposed periodicity of some temporary stars.

It is now maintained that none of the temporary stars are new originations, and that none of them have disappeared from existence, if even from visibility. That occurring in the Northern Crown is still telescopically visible; and it is maintained that the new stars of Tycho and Kepler may still be seen. In fact, the belief exists that the same stars had previously blazed forth more than once — that of Tycho in 945 and 1264, and that of Kepler in 393, 798 and 1203. In this view, temporary stars are only variable stars with very long periods. But this theory needs to be confirmed.

I think these phenomena can better be coördinated with the general tenor of change resulting from the genetic development of cosmical bodies. As every cosmical body is, in one stage of its history, thermally luminous, and at another, dark, there must be an era in the lifetime of each dark body, when it is passing from the condition of a luminous to that of a darkened body. There must be many stars at present in this transitional stage. There must be many more which have served as centres of planetary motion, but have since cooled to a state of darkened invisibility. There is no reason to assume that most stars are luminous. It is probable that space is strewn with planetized suns as well as planets and satellites. There are as many stages of evolution beyond the luminous stage as there are characteristic of it. There must be many dead moons lying unburied in the broad fields of space. Indeed we may conceive immensity like the soil on which human races tread, to be more densely populated by the dead than by the living. We dwell in a cosmic cemetery, and the ashes of worlds once quick with life strew the pathways of the burning and shining lights.

There are three ways, under this conception of things, for explaining the phenomena of a temporary star — or

one which bursts forth into visibility and brilliancy in a new place, and after a time disappears:

(1.) Collision of a precipitated planet. I have stated that all our planets must be tending toward precipitation on our sun. It may be that after our sun is cooled and darkened, some planet will yet remain to be reunited with its ancient mother. The reunion will not result from the direct fall of the planet toward the sun, but from a spiral descent. With ever-increasing velocity the planet will approach the central body, and will finally touch it. If both bodies are solidified, a degree of friction will be developed almost exceeding computation. If revolving wheels sometimes ignite the lubricating substances about their axles, what will occur when two planets crash together? The solidity of the rocks will seem but fluid. The planets will melt together with a grinding, crushing and heat-developing force which will make them one, and will rekindle their extinguished fires. Fusion and even the volatilization of portions of the matter must be the consequence. To an observer from a distant planet a new star would appear. Spectroscopically examined, its light would reveal a mixed condition, partly fluid, partly vaporous; or fluid and vaporous alternately, according to the varying character of the luminous matter turned toward the observer. Such phenomena have been noted in connection with the temporary star which appeared in the constellation Cygnus in November, 1876. An objection to this mode of explaining temporary stars lies in their brief duration. A pair of united worlds thus made incandescent would require ages for the dissipation of their heat. Such an event would rekindle an extinguished star to shine permanently during human epochs; and possibly some of our stars are old ones thus relighted. It is still possible that the precipitation of smaller masses of mat-

ter should originate incandescence of a more temporary character.

(2.) Eruptive action on an incrusting globe. In all stages of our earth's incrusted history, the disturbances of the crust through tidal action and shrinkage have opened outlets for included molten matter. Every geological period has been marked by the outflow of molten fluid, to some extent. But the largest escapes of melted lava have taken place toward the close of the Tertiary Age. American geologists have called attention to the vast extent of superficial sheets of ancient lava on our Pacific slope;* and Professor Geikie has collected the evidences of a similar and apparently contemporaneous efflux of lava over northwestern Europe, and regions since covered by the North Sea and the north Atlantic. In America these lava sheets spread over large areas, ranging from the valley of the Columbia River to Arizona and New Mexico, and as far east as the Rio Grande of Texas. In some places, cañons four thousand feet deep have been cut through by subsequent erosions. Now, it is apparent that when a sheet of glowing lava was spread rapidly over hundreds of thousands of square miles, the dark planet became again luminous to far distant observers. An enormous evolution of gaseous products must have accompanied the flow of the lava. The luminous phenomena must have endured probably for some weeks if not months; but the length of the period of luminosity could not have approximated that resulting from the precipitation of a planetary body. Now, if an ancient darkened and incrusted sun or planet should undergo, in the

* See especially Jos. Leconte, *On the Great Lava Flood of the West*, Amer. Jour. Sci., III. 167–80, 259–67, March and April, 1874. See also J. D. Whitney: *Geology of California*, and the various Government Geological Reports. There are some, also, who still hold to the primitive molten fluidity of all granites and many ancient schists. See Address of C. H. Hitchcock at Minneapolis, *Science*, ii, 223–7, 31 Aug., 1883.

distant heavens, an experience similar to that which seems to have befallen our planet in the later stages of its history, there must have been revealed to human eyes a spectacle somewhat similar to that which we have witnessed in the phenomena of "temporary stars."

(3.) It is also conceivable that a rekindling of a darkened sun or planet should result from the impact of a wandering cometary body. It is even supposable that a luminous star, too small or too distant to be visible, should be increased in brilliancy by such a collision to an extent which would render it visible to human eyes. If, however, so great an increase of brilliancy should be caused as marks the usual progress of a temporary star from invisibility to a star of first magnitude, there would seem to be implied a quantity of evolved heat which could not be radiated during the ordinary continuance of a temporary star.

I have myself adopted the second explanation as the one most probable. Every cosmical body must normally pass through the incrustive and eruptive stage; but we are not so certain that every one is destined to a rekindling through impact of descending matter.

3. *Variable Stars.*—Those stars which alternately increase and diminish in brilliancy must present some special conditions admitting of correlation with the progress of cosmical development. More than twenty of them have been shown to possess fixed periods of change, varying from about two days and twenty-one hours to 495 days.* Several of them complete their periods with uniformity reaching to a minute, and even a second, of time. Nothing but axial rotation of the body, or orbital revolution of an occulting body is conceivable as the basis of such punctuality. In some cases, however, as in that of Algol, the period is too short to ascribe, with probability, to oc-

*Argelander, in Humboldt's *Cosmos*, iii.

cultations. It is therefore probable that the phenomenon is generally due, as Zöllner suggested, to rotation of bodies having sides of different degrees of luminosity.

But there is also a variable factor in the periodicity of most variable stars. The maxima attained are not always of the same brightness; nor are the minima always the same. Sometimes the progress toward either extreme is marked by stages more or less irregular, and more or less differing in different periods. These phenomena point to changes in the brilliancy of the light received from the same hemisphere. It is highly improbable that these irregular fluctuations are caused by the transit of dark bodies. There must be variations in the intrinsic luminosity of the same regions.*

Now, the sun is a star near enough for closer study. The sun's disc is generally mottled by the well known solar spots. The number of spots has recently been shown to increase and diminish in a fixed cycle of about eleven years. As the solar light must be somewhat diminished by the presence of spots, it is apparent that the sun has a period of about eleven years. It is not at all improbable that the darkening effect of the spots may continue to increase until the diminution of light at times of greatest maculation shall become distinctly marked. With the thickening of the photospheric envelope, and the increase of resistance to the outbursts of the internal darker gases, the violence of the action accompanying the outbursts will increase; just as the most copious outflows of lava on the earth's surface took place after the crust had become comparatively rigid. Our sun would thus be unquestionably a variable star; and it is apparent that the initiatory stage of such a condition has already arrived. But it is further equally conceivable that maculation might

* On the causes of the variability of stars see Pickering, *Proc. Amer. Acad. Arts and Sciences*, xvi.

constantly predominate on one side during one or two generations of men. Such a condition would give a shorter period, determined by the sun's axial rotation. Or, variations in the depth of the maculations on the brighter or the darker side might cause irregular progress toward maximum or minimum brightness. These considerations applied to the variable stars of our firmament would seem to offer a plausible explanation of all the phenomena.

The question whether the variable condition attends upon a more or less advanced stage than that presented in stars with steady light can only be answered when we know the cause of the spots. It is generally admitted at the present time, that their existence depends on the outburst, cooling and descent of heated gaseous matters from the region within the solar photosphere. Father Secchi, speaking of the connection between the spots and the protuberances, says: "The spot is formed by the matter itself which the eruption projects upon the solar disc. The dark region is due to the absorption exerted by the vapors issuing from the bosom of the sun and interposed between the observer and the photosphere."* The theory of Faye differs in supposing the rupture in the photosphere to result from a vortical disturbance in that layer, which carries cooler vapors down; while Professor Young favors a slight modification of Secchi's theory. All these views make the spots depend on the superficial accumulation of vapors relatively cooler than the photosphere in whose depressions they rest. The diminished luminosity of the spots is due, therefore, to the high absorptive power of their substance; and this results from a relation of temperature. An increased efficiency of the cause or con-

* Secchi: *Le Soleil*, 2d ed. 1875–7, ii, 184. See also, Faye, *Comptes Rendus*, Jan. 16 and 23, 1865, and July 27, 1868, Tome lxviii, p. 197; Newcomb: *Popular Astronomy*, 280–2; Young: *The Sun*, 128, 175; Langley, in Newcomb's *Popular Astronomy*, 280–2.

dition of cooling of the ejected (or accumulated) vapors would increase the maculation, and in this view, one suggestion would be that excessive maculation marks an advanced stage in solar life. But it appears that maculation is a *differential* phenomenon. It results from the difference in the temperature of the subphotospheric region and the region exterior to the photosphere ; and this could be greatest by a more intensely heated interior as well as by a cooler condition of the surrounding atmosphere. It was the opinion of Father Secchi,* nevertheless, that maculation is a phenomenon of advanced solar life, and that progressive refrigeration must tend to increase it. Should this be a true conclusion, our sun is destined to become more distinctly a variable star in some future age ; and we may regard such stars as Beta of the Lyre and Mira of the Whale as more advanced in development than our own sun is. This, however, is a question which must be left, for the present, little better than a matter of conjecture. Algol, meantime, which varies with exact regularity and in short periods, is said to be distinctly a star of Secchi's first type ; and is to be associated, therefore, with Sirius and Vega. Its variability I have thought probably ascribable to rotation of a body of different luminosity on different sides.

It was Zöllner's suggestion that a variable star is a body reduced to a liquid state, with floating slags dimming the light on certain sides. This is akin to my suggestion respecting temporary stars, and seems a very rational explanation. The floating slag, however, should have a more fixed position than can be conceived probable unless nearly the entire surface has become slag-covered. This, then, would be a state of incipient incrustation, while the temporary star would exemplify an incident in advanced incrustation.

* Secchi: *Le Soleil*, ii, 456.

4. *Gradations of Stars.*—Every one has remarked the fact that certain stars, like Sirius, shine with a white light; others, like Capella, with a yellow light, and still a few others, with a ruddy light. Father Secchi showed that these three classes of stars afford three classes of spectra. As the spectrum depends on conditions of existence of a source of light, in reference to temperature, envelopes and pressure, the variously colored stars must exist in different conditions. In order to learn how far the spectroscopic characters of the stars furnish data for coördinating them in a genetic series, I present a condensed statement of the characteristics of the four or five classes of stars pointed out by Father Secchi* in his beautiful work on the sun.

First Type.—This embraces most of the *white stars*, such as Vega, Altaïr, Regulus, Rigel, the stars of the Great Bear with the exception of *a*, those of Serpentarius, etc. The class includes about half of the stars. Though commonly called white, they are, in reality, faintly blue. The remarkable variable star Algol seems to belong here. The spectrum in this class presents a group of seven colors interrupted by four dark lines, one in the red, another in the green-blue and two in the violet. These all belong to hydrogen, and coincide with the four brightest lines of this gas, when existing at a high temperature. Besides these broad fundamental lines, the brightest of these stars afford a very fine dark line in the yellow, which appears to coincide with sodium; and in the green, some still fainter lines which pertain to magnesium and iron. The most striking peculiarity of this type of stars is the breadth of the hydrogen lines; which tends to show that the ab-

*Secchi: *Le Soleil*, 2d ed., ii, 449-61; first announced in 1867, in *Catalogo delle Stelle di cui si è determinato lo Spettro luminoso all' osservatorio del Collegio Romano.* See the substance of Father Secchi's views in Schellen: *Die Spectralanalyse*, and the English translation, Am. ed., *Spectral Analysis*, 342-50.

sorbent layer possesses great thickness and exists under considerable pressure.

Second Type.—This embraces the *yellow stars*, like Capella, Pollux, Arcturus, Aldebaran, Alpha of the Great Bear, Procyon, etc. Arcturus, however, approaches the third type, while Procyon approaches the first. The spectrum is perfectly similar to that of the sun. This class embraces about one-third of all the stars.

Third Type.—These stars are all variable. In color they range from red toward orange. The type includes Alpha of Hercules; Beta of Pegasus; Omicron (or Mira) of the Whale; Alpha of Orion; Antares, etc. There are about thirty of first importance, and one hundred in all. The fundamental dark lines are the same as in the second type, but there are also present numerous nebulous bands which divide the spectrum and make of it a sort of colonnade illuminated from the side of the red. These spectral zones depend on variations in the stars, and these depend on the more or less absorbent action of their atmospheres. At the bottom of the solar spots a spectrum is obtained more profoundly rayed, and crossed also by dark bands. These stars then appear to owe their spectrum to an absorption analogous to that produced in the solar spots. If, therefore, our sun had everywhere an absorbent layer like that exposed in the spots, it would present the same aspect as the stars of this class. The most conspicuous lines are those of magnesium, sodium and iron. They are rather bands than lines, since they are broad, and shaded along the edges. This seems to indicate a powerfully absorptive atmosphere. There are also fine hydrogen lines, but they do not dominate as in the first two types. This gas certainly exists in these stars, but its lines are partially reversed, as happens in the spectrum of the solar spots. Most of the dominant lines belong to metals which have been found in the sun.

The spectrum is the same as that of the sun — or rather Arcturus — but profoundly divided by nebulous lines due probably to oxides. This indicates a temperature less than that of the sun.

The stars of the second and third types seem to differ simply in the thickness of their atmospheres, and in the discontinuity of the photosphere in the third type. These should have, then, variable spots like those of the sun, but of vastly greater dimensions, or even completely enveloping the star, forming a general layer more absorbent and less heated.

Fourth Type.—This consists of about thirty stars of blood-red color. The spectrum contains three fundamental bright bands, yellow, green and blue, not reducible to the preceding type, for the distribution of the light is entirely different. They are brightest on the side toward the violet, and fade gradually in the opposite direction. Some yield a faint trace of red. Some of the dark lines coincide pretty well with the third type, but the spectrum as a whole is that of a gaseous body rather than one of absorption. If considered an absorption spectrum, it presents the characteristics of carbon compounds, such as are yielded when a succession of electric sparks is passed through vapor of benzine and atmospheric air.

Fifth Type.—This consists of few stars, including Gamma of Cassiopœia and Beta of the Lyre, a variable star. It affords a direct hydrogen spectrum. The first named, according to Huggins, gives a spectrum in which the bright lines Hα (red) and Hβ (greenish blue) are visible in the places of the dark lines C and F. A bright line in the yellow, in place of D, is also suspected. The star Eta Argus gave a spectrum also, in which some of the most intense of the nitrogen lines were seen as bright lines. Two variable stars have been seen to give also a

direct but discontinuous spectrum — one in 1866, in the Northern Crown; the other R Geminorum. The temporary star in the Swan had also a similar spectrum. It seems, according to Secchi, to imply a rapid combustion at some former epoch — the light, probably, having been many years in reaching us.

The stars in the constellation Orion present still other peculiarities. They belong to the second type in the extreme fineness of the lines, but are quite exceptional in the nearly complete absence of the red and yellow. All the stars of this region present a double character: (1) They have a very pronounced green tint. (2) Their spectral lines are so fine that it is difficult to separate them. On the contrary, the region of the Whale and the Po contains a very large number of yellow stars. This distribution, says Secchi, cannot exist by chance. It depends, undoubtedly, on the nature and the state of the substances which fill different parts of the universe.

No inherent improbability exists that the distribution of the different substances is somewhat different in regions remote from each other. But we know too much of the uniformities pervading the widest regions of space to believe that differences of substance can produce any fundamental peculiarities such as characterize the various types of stars. These peculiarities, in all probability, arise from different conditions of the common substance. There are contrasts of condition, therefore, corresponding to the colors of the stars. Whether the different conditions are successive in the progress of a cosmical evolution is an unsolved problem. It may be noted, however, that the series of colors, white, yellow and red, is a succession presented by successive stages of cooling from a white heat. Still, these stages as observed, occur in the cooling of a body whose temperature is low enough to permit it to retain a solid condition from the first to the

last; while suns, in all their luminous stages, are supposed to be vastly hotter than white-hot iron. Would this succession of colors be presented in stages of cooling, all of which are far above the temperatures of molten iron? Or, is the supposition erroneous that all the stellar matter determining the color of the light is so intensely heated?

There is a time in the history of a sun when intense heat has resulted from the gravitational condensation of its parts. Most of its substance exists in a gaseous or even dissociated condition. It is improbable that a high degree of luminosity characterizes such matter. But the peripheral region must always experience important effects from radiation. It seems very improbable that the general temperature of the mass could be so high or so universally distributed that the surface should not be chilled to the point of formation of fire mist. A zone of fire mist would envelop the gaseous globe like a skin. Fire mist is simply gas cooled till minute liquid particles come into existence which float in a common atmosphere of gases not yet condensed. In the liquid or solid state, luminosity is greatly increased, even at a lower temperature. In such a zone of fire mist, a circulation of particles must be in active progress Coalescence of particles, as in a cloud of aqueous vapor, would give rise to drops which would descend like rain to the lower surface of the photospheric fire mist. They would even penetrate the hotter, gaseous nucleus for a limited distance, but would soon be dissolved to gas and returned to the zone of the fire mist. By this process, long continued, this photosphere would be deepened, and the nucleus correspondingly diminished in volume. In the course of time, the nucleus would be wholly replaced by fire mist; and then would begin that central accumulation of a liquid core of which I have elsewhere spoken. The proper life of a sun is therefore divided into two stages, in the first of which a gaseous nucleus

goes on diminishing, and in the other of which a molten nucleus goes on increasing.

But in either stage, the photospheric zone is reduced to the point of liquefaction of a considerable proportion of its substance. Being liquefied, its temperature must be such as is compatible with the existence of matter in that state. According to this reasoning, the condition of the photospheric particles might be compared with that of a mist of molten iron. It might possess the temperature and the luminosity which belong to terrestrial substances at the temperature of a white heat. The deeper portions of the photosphere, however, must be more copiously pervaded by a gaseous medium at a higher temperature; and the entire gaseous nucleus, so far as I perceive, may subsist at any temperature compatible with the evidences bearing on the intrinsic heat of solar bodies.

But if the particles upon the outer surface of a photosphere may exist at the temperature of the white heat of molten iron, it seems possible they may also exist as solid particles at the lower temperature which emits a yellow, or even a ruddy, light. In this view, the colors of the stars may truly denote successive stages in a process of cooling. Whether such a conclusion is compatible with the evidences on which scientific opinion has generally agreed to ascribe a much higher temperature to the surface of the sun, is a question for the future to decide. It will be noticed, however, that the general heat of the solar surface is constituted partly by the higher temperature of the gaseous medium from which the photospheric particles are generated. This may also be added, that on most of the solar bodies the enormous force of gravity would have the effect of raising the point of liquefaction from a gas, and the enormous pressure of the superincumbent atmosphere, however rarefied by heat, would increase this effect; so that the incipient molten stage

would imply a higher absolute temperature than on the earth. It is still true that the lower limit of luminosity, and probably all higher degrees of it, would be determined by the rate of molecular vibration, independently of the condition of the matter as to fluidity. For this reason nearly all substances might require an intense white heat even for liquefaction, and a vastly higher heat for conversion into the less luminous condition of gaseity.

In view of the whole range of considerations, I shall assume provisionally that the various colors of the stars exhibit a gradation in the cooling process.

A few further obvious suggestions may be made in this connection. In the earliest stages of photospheric existence, the fire-mist film would be so thin as to possess a lower degree of luminosity than at a later stage. The light emitted would be thin and leaden in hue. It is quite conceivable, also, that causes may exist in particular cases, for changes in the hue of the light resulting from diminished, as well as increased, depth of the photospheric zone. A star, at one time yellow, might recede to the white stage. A white star might recede to the bluish or leaden stage by increase of its general temperature. Thus, it is possible the reputed changes in the colors of certain stars, which are of a retrogressive significance, may be interpreted in harmony with the provisional conclusion which I have enunciated respecting the meaning of color gradation among the stars.

But, if we admit that the white, yellow and red colors of the stars represent as a general, though not invariable rule, successive cooling stages, it remains to ascertain whether these stages all appertain to photospheric life, or characterize, in part, the later stage, incandescent incrustation; and also, whether, if one or all of them appertain to photospheric life, it is that period which precedes or follows the beginning of liquid nucleation. We dis-

tinguish three phases in the life of a self-luminous cosmical globe: (1) The gaseous-nuclear phase; (2) the liquid-nuclear phase; (3) the incrusted phase. During the first two, or characteristically solar, phases, a photosphere exists, consisting of particles of liquid or solid matter, and giving by itself a continuous spectrum; but an absorbent atmosphere still existing in abundance, the resultant spectrum is crossed by dark lines. The volume and density of the enveloping atmosphere are so great that the dark lines possess a greater breadth than in the solar spectrum. During the third phase, the spectrum should be continuous; but still, at the supposed temperature, a dense, heterogeneous and absorbent atmosphere might still impress dark lines upon the bright continuous spectrum. Now, the spectral conditions of the first two stages are exhibited by the white and yellow stars — the white stars giving the broadest dark lines, and thus evincing the greatest depth of atmosphere. We must conclude that these two stages belong to the photospheric period. The indications of the few red stars are ambiguous. Their spectrum is characterized by dark lines, but Father Secchi was of the opinion that they offer some indications of more predominant gaseity than the others. Their red color may result from some other cause than their advanced stage of cooling. But since the incrusted state must be accompanied still by a voluminous envelope of gases, and since ruddy light is certainly expressive of diminished incandescence, while further, the light of the crust, with diminished intensity, would be less able to contend with the absorbent and luminous powers of the atmosphere, I shall venture to assume, though provisionally, as before, that the ruddy stage is generally to be interpreted as the early incrusted phase.

The variable ruddy stars will represent earlier phases — sometimes an advanced macular condition, and in some

cases a phase of incipient incrustation; while the temporary stars are phenomena of advanced incrustation.

5. *Indications of Incipient Stellation.*—Certain phenomena presented by celestial objects not recognized as well formed stars may be interpreted as characteristics of *incipient* stellation. Certain dense star clusters, as well as most of the so-called resolvable nebulæ, present continuous spectra. Such a spectrum is yielded by incandescent solid or liquid bodies. When such a body is surrounded by gases of lower temperature, dark absorption lines appear in the spectrum; but if the surrounding gas itself is intensely heated, it imparts its own bright lines to the spectrum, and these then appear superposed over a continuous spectrum. But there is a certain intermediate state of luminosity in the envelope in which its absorbent power is just neutralized by its emissive power, and its effect on the spectrum of the inclosed molten material disappears. Such seems to be the condition of the gaseous medium in the star clusters and resolvable nebulæ referred to.

At an earlier stage, the emissive property of the heated atmosphere preponderates, and the spectrum is one of bright lines over a continuous spectrum. The preponderance in the emissive power of the gaseous medium may depend on the relatively low temperature of the enveloped portions; and this may depend on the comparatively low degree of condensation as yet attained. A later period, therefore, would witness a greater degree of condensation, intenser central heat, and a relatively more powerful luminosity. That is, a more advanced stage would increase the amount of fire mist and its relative luminosity, besides reducing the volume and pressure of the envelope, and thus establish those relations which produce a continuous spectrum crossed by the dark lines of an absorbent medium. This description of spectral power is possessed by

"Planetary Nebulæ" and "Nebulous Stars." We may, therefore, unite with Sir William Herschel in considering these forms as stages of cosmical development, showing a passage from nebular to stellar life.

§ 2. COSMOGONIC CONDITIONS OF NEBULÆ.

Le monde s'élargit donc à nos yeux; le système solaire ne nous paraît plus que comme un point dans l'espace. Quelle différence entre ces idées si larges et celles qui autrefois limitaient le monde au notre globe. * * * Il est probable que la réunion des grands étoiles qui environnent notre Soleil n'est qu'un des amas qui forment la Voie lactée, et que vu d'une certaine distance, cet amas apparaîtrait comme une tache plus blanche dans la Voie lactée elle-même.—SECCHI.

The typical nebula is one which is irresolvable and shines with a faint light, affording a spectrum of one or more bright lines. The brightest of these lines, with a wave length of 5,005, is coincident with a nitrogen line. The second, when others exist, has a wave length of 4,957 (Angström). The other two are coincident with hydrogen lines Hβ or F and Hγ near G. This spectrum is sometimes superposed on a faint continuous spectrum.

In some careful investigations recently made upon the nebula in Orion by Mr. Huggins* a fifth relatively strong line was observed in the ultra-violet, of wave length 3,730, which appeared to correspond to ζ in the typical spectrum of white stars.† Mr. Huggins states, also, that he cannot say positively that the hydrogen lines between Hγ and the fifth nebular line are wanting, and he even suspects their presence, as also others beyond the fifth nebular line. Mr. Huggins further says, that outside of the usual stronger continuous spectrum, which he attributes to stellar light, he suspects an exceedingly faint trace of a continuous spectrum. Dr. Draper's photographs show also a continuous spectrum from two condensed portions just

* *Proc. Roy. Soc.*, March 16, 1882, *Nature*, xxv, 489.
† *Phil. Trans.*, 1880, p. 677.

preceding the trapezium. These observations show the nebular spectrum to be less simple than had been supposed, and demonstrate, apparently, the presence at least of hydrogen and nitrogen. Frankland and Lockyer have shown that the spectrum indicates a lower temperature than exists in our sun, and a remarkably low density.

The presence of bright lines indicates that an important portion of the nebula is gaseous, while the faint continuous spectrum, when present, seems to indicate the existence of incandescent solid or liquid matter. Though Mr. Huggins, an eminent authority, inclines to attribute the continuous spectrum to stellar light, I see no strong reason in the phenomena for denying that both solid and liquid matter exist in a luminous condition in most nebulæ. Assuming, as I have done, that nebular history begins with the aggregation of cold matter, some of which is analogous to that forming meteoroidal trains, there would naturally arrive a time when, by collision of hard constituents, and condensation of gaseous constituents, heat would be developed. This would sooner or later originate gaseous luminosity; and this is the typical condition. But from this, by peripheral condensation, must arise some amount of fire mist; and the very process of volatilization implies also a stage of fusion passed. This fire mist, and this antecedent liquidity would afford the continuous spectrum. The double spectrum is shown not only in some continuous nebulæ, but also in a small number of nebulous stars. Some nebulæ, as heretofore stated, seem to undergo a process of segregation of parts by curdling and accumulation apparently around nuclei. They become then clusters of nebulous stars. Certain so-called resolvable nebulæ present this condition. This seems rather a collateral than a consecutive phase, since, as I have before indicated, it may be regarded as characterizing nebulæ which do not rotate and annulate.

Finally, we have to consider a prenebular stage. Before the matter of the nebula is collected in form it must exist in a formless or chaotic stage. I have already described the phenomena which I suppose to be connected with prenebular conditions. The matter is diffused; it is cold; it is composed of mineral substances aggregated in masses, at least in part, which are drawn together by mutual attractions, forming distinct groups or swarms which are further aggregated successively, until those vast fields of cosmical stuff are accumulated which become luminous nebulæ.* Perhaps generally the aggregation into masses is very limited, and the matter exists mostly as widely scattered particles or molecules. This diffused and unorganized condition of primitive world stuff answers to the chaos conceived by Kant, though he banished it from the realm in which cosmical organization has taken place, while the present conception supplies all the spaces in the midst of the worlds with these seeds of cosmical organization.

I am not aware that it is possible to trace inductively the history of world formation to any remoter point. It is certainly possible to conceive these cosmical atoms as arising out of some transformation of the ethereal medium, and more than once expression has been given to such a speculation.† But we know too little of the nature of ether to ground a scientific inference of this kind; and we certainly have no knowledge or conception of any condition of matter antecedent to that in which it possesses resistance, weight and inertia. The attempt to go farther involves us in speculations of a metaphysical character respecting the ultimate nature of matter, and this is a field of inquiry which it is not proposed to enter.

* See more specifically, Part I, ch. i, § 7.

† See the references pp. 49, 50, 61. A later article by A. S. Herschel appears in *Nature*, xxviii, 294-7, July 26, 1883.

CHAPTER II.

THE COSMIC CYCLE.

Facies totius Universi, quamvis infinitis modis variet, manet tamen semper eadem.—SPINOZA.

Herschel, en observant les nebuleuses au moyen de ses puissans télescopes, a suivi les progrès de leur condensation non sur une seule, ces progrès ne pouvant devenir sensibles pour nous, qu' après des siècles; mais sur leur ensemble, comme on suit dans une vaste forêt l'accroissement des arbres, sur les individus de diverses âges, qu'elle renferme.—LAPLACE.

§ 1. THE KEYS OF COMPARATIVE GEOLOGY.

THE views presented in the foregoing chapters direct attention to some of the sublimest considerations which can occupy the human mind. We rise from the contemplation of the interests and affairs of the individual or of the human race, not alone to that larger scope of events which constitutes the lifetime of the habitable globe which endures while generations and nationalities come and disappear; but that grander conception of the cycle of events which constitutes the round of evolutions awaiting every aggregation of cosmic matter in the material universe. I wish to impress this thought of the unity of cosmical history, and lead my reader to an impressive apprehension of the vastness of the scheme to which he belongs, and of the exaltation of constituting a part of a scheme so vast.

The possibility of rising to a comprehension of a system of coördination so far outreaching in time and space all range of human observation, is a circumstance which signalizes the power of man to transcend the limitations of changing and inconstant matter, and assert his superi-

ority over all insentient and perishable forms of being. There is method in the succession of events, and in the relation of coexistent things, which the mind of man seizes hold of; and by means of this as a clew, he runs back or forward over æons of material history of which human experience can never testify. Events germinate and unfold. They have a past which is connected with their present, and we feel a well justified confidence that a future is appointed which will be similarly connected with the present and the past. This continuity and unity of history repeat themselves before our eyes in all conceivable stages of progress. The phenomena furnish us the grounds for the generalization of two laws which are truly *principles of scientific divination*, by which alone the human mind penetrates the sealed records of the past and the unopened pages of the future. The first of these is the law of evolution, or, to phrase it for our purpose, the *law of correlated successiveness* or *organized history in the individual*, illustrated in the changing phases of every single maturing system of results; as organic structure, human civilization or world-growth. The second is the law of *correlated simultaneousness*, or *parallel history in many individuals*, whereby many particular instances of progressive development in different stages of maturity are presented simultaneously; as the different persons in a large city exemplify simultaneously the stages of development attained by any individual on every day of his life.

Thus, by virtue of these two laws, each individual undergoing an evolution finds at every moment its entire past and future recorded in the present of other individuals belonging in the same category. The man of mature years can turn in one direction and study the stages which he has passed through from earliest infancy; and in the other direction, the stages which, in the course of nature, he will pass through to remotest old age. I go into the forest, and

within an hour trace the life history of an oak all the way from the acorn to the crumbling veteran of three hundred years. An ephemeron intelligence could thus write the history of a tree destined to endure a thousand years. It is so in the history of a planet. Man is an ephemeron compared with the lifetime of a world; but while he endures, he notes thousands of worlds in all the different stages of world-life, and, selecting a series of examples, he runs them on a continuous thread, and has a tale of evolutions which span a million years. Individual histories have begun at different periods in the lapse of time; and individual histories, whether simultaneously begun or not, have been accelerated or retarded by differences in the modifying conditions.

Our earth has reached a certain stage of development. It happens at this epoch to be a habitable world. It is supposable that its present state has persisted from eternity; and this was the belief of some of the ancients, as well as a few of the moderns. Limited observation, however, shows that changes are taking place—that a history is in progress, and the mind demands the past of this history—that which lies back of the observation of the individual, or even of the race. Now, availing ourselves of the *law of parallel history*, we study the phenomena of beach erosion and detrital accumulation, and see in these a picture of Silurian times—of geologic changes consummated thousands of years before even our race had an existence. This is pure geology. But nothing in the existing phases of the planet can reveal the history of events which *transformed* the planet. Bodily transformations obliterated all records of what was past. Geology has perpetuated terrestrial history only by the fixed forms of enduring rocks. But we find in igneous masses intimations of an older state, whose records were written upon fluid matter, to be inevitably effaced. Here is the

limit of possible geology. But we learn that our earth, as a whole, is but one of a series of planets; that these planets, from their common physical relations, must have had a *common* history; that before they were planets, they belonged to a category of existence of which the sun is a type and a remnant; that, probably, in some remoter epoch in the past eternity, all the suns belonged to a category of existence now exemplified in irresolvable nebulæ; and we learn that all these conditions are phases in the consummated history of our world — that the investigation of them is at the same time cosmogony and geology.

The fundamental data of this comparative science of world growth have been already passed under review.* The first group of data unites the earth, the planets and the satellites in a single category of existence. The community of movements, forms and conditions is such that we feel borne to the conclusion that whatever may be determined as to the past or future conditions of our world must be also conditions in the life history of each of the other planets. These relations have arrested the attention of all students of nature, and have produced in the most thoughtful minds an irresistible conviction that the members of the Solar System constitute but one family — that all the planets and satellites must have had a common starting point. This conviction has found expression in the theories propounded by Kepler, Newton, Leibnitz, Kant, Herschel and Laplace.

The most recent results of speculation concerning the progress of cosmical evolution I have set forth in preceding chapters. It will be of interest now, to glance from our elevated standpoint over the whole realm of cosmical existence and note synoptically the stages attained by the different orders of worlds in human times, and then to

* Part II, chapters i–iv.

follow the current of events onward from our present terrestrial condition toward some far-off cosmical finality.*

§ 2. THE FINAL GENERALIZATION.

Alles was endlich ist, was einen Anfang und Ursprung hat, hat das Merkmal einer eingeschränkten Natur; es muss vergehen und ein Ende haben.—KANT.

1. *Stages of World-life.* — The deepest principle of change in cosmic existence is expressed by the word *cooling*. The broadest physical generalization to be drawn from the phenomena of the cosmical realm is the affirmation of progressive reduction of temperature. The history of a world is a history of cooling. All other world-making activities come into play concomitantly. If the process of cooling transforms also a vast amount of mechanical energy into the form of heat, it is always, and necessarily, less in amount than the energy lost in transforming it.

The three great cosmic forces are *heat* and atomic and molar *attractions*. To these should probably be added *repulsions*.

A world's lifetime, with its incidents and consequents is but a progressive cooling. Every individual world in the established order of events, passes or may pass, successively through all the stages and phases known to cosmogony. Cosmic lifetimes have begun at different epochs, and proceed at different rates of change. Some

* The present writer's first published attempt to generalize the whole course of cosmical history was a brochure entitled *The Geology of the Stars*, 32 pp., 12mo, Boston, 1872, being No. 7 of "Half Hour Recreations in Popular Science," pp. 255–286. Almost simultaneously appeared Mr. Stanislas Meunier: *Le Ciel géologique, prodrome de Géologie Comparée*, Paris, 1871. A descriptive treatment of the early and remote future history of our world, with glimpses of the comparative geology of our system was presented by the writer in *Sketches of Creation*, 12mo, pp. 459, with Illustrations, New York, 1870. He has also discussed the subject in *The Unity of the Physical World*, Part I, *Facts of Coexistence*, Part II, *Facts of Succession*, Meth. Quarterly Review, April, 1873, and January, 1874.

began so far back in eternity or have proceeded at so rapid a rate, that their careers are brought to a conclusion in the passing age. Some are even now awaking into existence ; and it is probable that worlds are beginning and ending continually. Hence cosmic existence, like the kingdoms of organic life, presents a simultaneous panorama of a completed cycle of being. A taxonomic arrangement of the various grades of animal existence presents a succession of forms which we find repeated in the embryonic history of a single individual, and again in the succession of geological types ; so the taxonomy of the heavens is both a cosmic embryology and a cosmic palæontology.

In endeavoring to present by way of résumé, a systematic or developmental arrangement of cosmical conditions, our thoughts fix at once upon four general stages of world-life. These are first, the Chaotic or Prenebular ; second, the Nebular Stage ; third, the Solar Stage ; and fourth, the Planetary Stage. Under the last three we may readily discriminate several phases of progress. It probably is not possible, in the present state of human knowledge, to arrange these phases in a final consecutive order. Probably some phases are parallel with others, instead of consecutive. Nevertheless, a developmental arrangement is a desideratum ; and the inexpert reader will be thankful for a systematic exhibit of the best results science has as yet attained, or even for the following résumé of the discussions and conjectures ventured upon in the present work.

I. CHAOTIC STAGE.

Cosmical dust. Cosmical atoms promiscuously dispersed in space ; gathering themselves in groups large and small ; forming *meteors*, *meteoroidal trains* and probably *comets ;* in their larger aggregations becoming nebular dust, either cold or partially heated.

II. NEBULAR STAGE.

1. *Normal Nebular Phase.*—Faintly luminous matter consisting perhaps of mineral mist formed of incandescent liquid or solid particles floating in a luminous, gaseous medium, or of stony particles and masses whose mutual collisions develop heat and incandescent gases. Spectrum consisting of one, two, three or four bright lines, or perhaps of five or more, revealing the presence of nitrogen and hydrogen, and sometimes superposed on a faint continuous spectrum. Density low and heat less than that of our sun. Exemplified in certain irresolvable nebulæ.

NOTE.—The thermal incandescence of the normal nebula remains to be fully established.

2. *Nebular Fire Mist.*—Mineral mist increased in quantity, but a gaseous medium still predominant. Condensation and evolution of heat in progress. Spectrum of bright lines superposed on a faint continuous spectrum, showing presence of fire mist.

A. Continuous fire mist. The nebular mass remains homogeneous and its luminous constituents mostly gaseous. Certain *irresolvable nebulae*, as H. 4,374. Also a small number of stars, as Gamma of Cassiopœia and Beta of the Lyre.

Annulations perhaps begin in this phase. The primitive nebula may thus be resolved into solar nebulæ in which other annulations succeed; or if the mass is insufficient, it may proceed with only the evolutions of a solar nebula. *Annular*, and probably *spiral* and *falcate* nebulæ belong here, the two latter illustrating a disturbed state of annulation. Saturnian rings persisting like a preserved embryo, exemplifying the *form* but not the stage.

B. Discontinuous fire mist. Phase parallel with A. Nebula undergoing segregation and accumulation around local nuclei without annulation. Also, entire nebulæ slowly condensing around single nuclei. Certain *resolvable nebulæ* (compare nebula in Draco).

3. *Nucleating Phase.*—Distinct central condensation.

Photospheric matter increased, but the gaseous medium predominant. Bright lines over a continuous spectrum. Sun systems and planetary segregations past the stage of annulation. *Planetary nebulæ*, especially H. 838, H. 464, H. 2,098 and H. 2,241.* Also *Nebulous Stars*, as H. 450.

4. *Nucleated Phase.*— Condensation more advanced. Temperature and luminosity of the fire mist so increased that the absorbent power of the gaseous atmosphere is precisely neutralized and the spectrum is continuous. Point of transition from bright-line spectra to dark-line spectra. Phase observed probably, in certain *star clusters*, and most *resolvable nubulæ*.

NOTE.—The continuous spectrum may, in some cases, be only apparent, the fineness of the lines rendering them invisible with existing instruments.

III. STELLAR STAGE.

1. *Sirian Phase.*— Increased condensation and increased heat. Atmosphere increased in volume and tension. Absorbent capacity exceeds the emissive. Spectrum continuous and crossed by four dark lines having an extraordinary breadth. *White Stars* (Secchi's First Type).

NOTE.—The mass of the star, independently of its age, would influence the tension of the absorbent medium, and hence the width of the dark lines. We cannot be certain, therefore, from spectroscopic indications, that this phase precedes the next. Guided by color alone, the white stars should precede the yellow.

2. *Capellar Phase.*—Absorbent atmosphere reduced in depth and consequent tension, to such an extent as to give very numerous dark absorption lines of normal breadth. Spectrum identical with normal spectrum of the sun. *Yellow Stars* (Secchi's Second Type).

Some fixed stars in the last two phases, the centres of cosmic systems. Some have attendant worlds still luminous. *Sirius* is a sun with four still luminous planets.

* These designations refer to Herschel's Catalogue of Nebulæ.

Procyon, *Rigel*, *Aldebaran*, *Arcturus*, *Antares*, *ζ Cancri*, etc., have each one or more. Some of these companions have still smaller attendants, as *μ Lupi*, *η Lyræ*, *ξ Cancri*, 12 *Lyncis*, *θ Orionis*. These are still luminous satellites.

3. *Solar Phase.*—Photospheric matter copious. Atmosphere in a high state of activity, and still causing a spectrum of dark lines. The heated nucleus ejecting gases through the photosphere, which fall back, on cooling, and form dark spots on the surface of the photosphere. Incipient variability.

A. Phase of the gaseous nucleus continually diminishing. Probably our own sun.

B. Phase of the molten nucleus continually increasing. This succeeding phase A.

4. *Variable Phase.*—Photosphere periodically darkened by the condensation of large amounts of macular matter. Probably approaching total liquefaction. Spectrum as in Second Phase, but with numerous nebulous bands brightest *on the side toward the red*. *Periodic* and *Irregular Stars* (Secchi's Third Type). Some variable stars probably advanced to incipient incrustation.

5. *Molten Phase.*—Photospheric matter exhausted by precipitation. Absorbent media greatly reduced. A molten globe. Spectrum continuous. Probably some of the *Star Clusters* and *Resolvable Nebulæ*.

6. *Incrustive Phase.*—Early periods of incrustation. The light becomes ruddy. Incipient darkening. Spectrum of dark lines, but crossed by three bright bands, brightest *on the side toward the violet*. *Red Stars* (Secchi's Fourth Type).

NOTE.—I am much in doubt concerning the proper position of the "red stars." Their spectra, unless some explanation can be given, would place them between the Nebular and Stellar Stages. I assume, therefore, that the early incrustive phase is one which presents the reproduction or fresh disengagement, of some enveloping

absorbent medium. I have already recorded my conviction that it is a phase of aqueous condensation and aqueous gaseity — the prelude of the stormy period.

7. *Eruptive Phase.*—Crust so darkened as to be invisible as a star; but disrupted at intervals, giving spasmodic luminosity, which shines through an atmosphere of aqueous vapor and gas. Spectrum continuous, and crossed by dark lines like the solar spectrum, with a superposed spectrum of four bright lines. *Temporary Stars*, also γ *Cassiopeiæ*, β *Lyræ* (variable) and η *Argus* (Secchi's Fifth Type).

NOTE.—The phenomena of a temporary star may recur many times during the progress of the planetary phases, and thus give the star a remotely periodic character.*

IV. PLANETARY STAGE.

1. *Jovian Phase.*—The incrustive phase has passed into the stormy phase. A water mist condenses in the peripheral regions, as formerly the fire mist appeared. It gathers into a vaporous envelope constituting a true atmosphere or nephelosphere. This precipitates an aqueous rain, the homologue of the molten rain of earlier times.

A. Phase of fading luminosity. Crust not yet darkened or cool enough to receive the rains. Phase of Jupiter.

B. Phase of the primeval ocean. Protophytic and later, protozoic life, on planets otherwise suitably conditioned.

2. *Terrestrial Phase.*—Aqueous precipitation periodical. Cyclonic movements of the atmosphere, perhaps the

* The writer is fully aware of the insufficiency of the known data for correlating the various phases of cosmical matter, and of the rashness of his own attempt to do what has not been attempted by the masters of stellar physics. We need to know much more yet respecting the relations of spectra to temperature, pressure and molecular arrangement; and also, in view of the analogies drawn from light in Geislerian tubes, more of the connection between the tension of the electric current and the temperature and density of the gas made luminous by the electric discharge. The reader, nevertheless, who will avoid placing too much stress upon the details of the foregoing arrangement, will obtain a correct impression of the great fact of progressive changes in cosmical matter.

homologues of those which cause solar maculations. Period of organic life, embracing its culmination. The *Earth*, and possibly *Venus* and some of the *satellites of Jupiter*.

3. *Martial Phase.*—Planetary senescence. Diminished vapors and infrequent rains. Encroaching cold. Decline of organic development. *Mars*, and possibly the *Jovian satellites*.

4. *Synchronistic Phase.*—Tidal retardation of rotary motion progressing, and reaching its finality. *Moon*, and probably all the *older satellites*.

NOTE.—This is not a true consecutive phase connected with the progress of inherent or developmental change, but a state growing out of relations to other bodies. It may be reached sooner or later, according to the efficiency of the tidal action exerted.

5. *Lunar Phase.*—Planetary death. Disappearance of aqueous vapors and total absorption of water and atmosphere. Extinction of organization. Final refrigeration, exemplified in the *Moon*. In bodies with an excess of water and air, the surface becomes ice-covered and the copious atmosphere remains laden with frozen vapors. *Saturn*, *Uranus* and *Neptune* and *their satellites*.

However conjectural some parts of the foregoing arrangement may be, there is little doubt that its general tenor expresses a fact in the aspects of the universe. This I have endeavored to explain and impress. We know enough of the phases of matter in the different provinces of space to feel certain that they represent progressive stages in the natural evolution of matter as such. Whether seen in nebula, star, sun, planet or satellite, it is a phase in a common history, the earliest periods of which are as truly a part of the history of our world as the achievements of Alfred the Great are a part of the history of communities of American birth.

6. *Some Final Deductions.*—These views are calculated to produce upon our minds a profound impression of

the unity of the universe, both in its spatial extent and its historical development. When we combine with these evidences the indications of the presence of a common ether or other luminiferous medium, and of the supremacy, everywhere, of the universal law of gravitation, we are placed in possession of an overwhelming demonstration of the identity of the government which controls natural events upon our planetary abode, and in departments of space so remote that light occupies hundreds of years in traversing the distance. Whatever intelligence, power or goodness may seem to be exemplified in the ordinations of terrestrial affairs, is not less certainly illustrated in the phenomena which we trace to the utmost verge of the visible universe, and to the remotest conceivable commencement of material history. The intelligent Power whose supreme control is recognized within the narrow limits of personal experience is ONE through stretches of space and time which, to human faculties, are infinite.

The study of stellar geology leaves us with another reflection. Every phase of matter seen in the universe is a transient one. The various phases sustain demonstrably some sort of historical relation to each other. These states of matter are progressive. We trace them backward toward earlier conditions — toward an earliest condition, beyond which we *know no possibility* of cosmical existence. From that condition to the present is but a finite career, however vast the interval appears expressed in numbers. The history began in time; it does not come down to us from eternity. The material *organism* is, therefore, originated in time. Now, when we carry our thoughts back to that primal condition indicated, we must necessarily perceive that it existed absolutely unchanged and unprogressive from all eternity, or the *matter itself* which exemplifies it did not exist from eternity. But we have not the slightest scientific ground for assuming that

matter existed in a certain condition from all eternity, and only began undergoing its changes a few millions or billions of years ago. The essential activity of the powers ascribed to it forbids the thought. For all that we know — and, indeed, as the *conclusion* from all that we know — primal matter began its progressive changes on the morning of its existence. As, therefore, the series of changes is demonstrably finite, the lifetime of matter itself is necessarily finite. There is no real refuge from this conclusion; for, if we suppose the beginning of the present cycle to have been only a restitution of an older order effected by the operations of natural causes, and suppose — what science is unable to comprehend — that older order to be a similar reinauguration, and so on indefinitely through the past, we only postpone the predication of an absolute beginning, since, by all the admissions of modern scientific philosophy, it is a necessity of nature to run down. No former condition is completely reproduced. The total energy in the cosmic organism diminishes. A finality is impending, and hence a past eternity would have sufficed to reach it an eternity since, and we should not be witnesses of the continued progress of events. Whatever process from an infinite beginning involved an end is now a process ended, not continuing. The conclusion is unavoidable that the cosmic organism began in time, and that the very existence of matter is limited in the past.

The dependent existence and finite origin of matter are revealed in its ultimate constitution. The scenes which we have been contemplating are characterized by ceaseless nutation and transformation. The very notion of an evolution presupposes this. The progressive activity of nature's forces continually rebuilds the material organism. The old disintegrates and reappears transformed. Nothing is permanent. The ponderous forms of

worlds come and go. Suns are kindled and extinguished. Constellations spread the floor of heaven for a time, to be swept away by the æonic march of events. In the progress of eternity how many cycles of world-life have been spent; what vicissitudes has each molecule of matter experienced; how many stations has it occupied, how many functions performed. But we pause. This very witness of cosmic changes testifies to something permanent and changeless. The molecule has not changed. As hydrogen, as silica, as water, or other form of matter, it maintains its identity in all the worlds, in all the remotest spaces of the realm of cosmic existence. It throbs in Sirius with the same signal as in Capella. Its vibrations are measured by the same infinitesimal in Orion and in the sun, and in the laboratory of the experimenter. The quartz molecule which forms the gravel of the garden walk is the same which slept for ages in the masses of Archæan quartzite. When the quartzite came into existence, the molecule was ancient. It had taken part in the history of the molten ages of the planet; it had been part of the primordial fire mist in which the first lines of cosmic organization were traced. It grows into nothing else; it grew out of nothing else; it is primordial, completed and perfect. It was not, like everything else, compounded; it was not evolved; it does not disintegrate or become effete. The mutations which we have traced belong to the *forms* of matter. The molecule belongs to a different category of existence. If we conceive the molecule resolvable into atoms, then the conclusion remains of the atoms. Between the changeful and the changeless is an infinite gulf. And with all their qualities of permanence and indestructibility and perfection and uniformity, the molecule has been multiplied by millions of millions of millions — each molecule cast in the same mould, endued with the same form, animated by the same energies.

How has it been multiplied? In a universe organized through processes of evolution, what is the origin of a thing unevolved? In a world of effects and causes, what is the cause of a thing which had no antecedent? Our thought here trembles on the primal verge of being. *Beyond*—is the abyss of nothingness; *here*—are the seeds of a universe. These are not grown in the nursery of the natural world.

Finally, as just intimated, the future life of cosmical organization is as clearly set within limits as its past. There is an ultimate goal toward which all cosmical matter is tending. That goal is not the actual condition of our world, for we see here everything in a state of change; and the moon exemplifies an ulterior state. It cannot be the Lunar phase, for even there solar light and heat, and terrestrial influences, and universal gravitation, and meteoric matter, and a pervading ether, are all conspiring to disturb the condition of absolute repose. The finality lies in the impenetrable darkness of the distant future. What it may be we can only conjecture; but one impending stage of all cosmical matter is positively written upon the face of the moon. Not only must our own planet reach finally that refrigerated and inhospitable condition, but the sun itself must ultimately fade to a darkened planet and become extinguished in the heavens.

These thoughts summon into our immediate presence the measureless past and the measureless future of material history. They seem almost to open vistas through infinity, and to endow the human intellect with an existence and a vision exempt from the limitations of time and space and finite causation, and lift it up toward a sublime apprehension of the Supreme Intelligence whose dwelling place is eternity.

PART IV.

EVOLUTION OF COSMOGONIC DOCTRINE.

Les Savants sont de nos jours *unanimes* à admettre que notre système solaire est dû à la condensation d'une nébuleuse qui étendait autrefois au-delà des limites occupées actuellement par les planètes le plus lointaines * * * La théorie * * * a été bien confirmé, et, pour ainsi dire, demontré par la découverte des nébuleuses gazeuses.— Le Père SECCHI.

PART IV.

EVOLUTION OF COSMOGONIC DOCTRINE.

WHEN a great theory has grown into existence, and the general assent of competent judges has converted a sublime conception from the state of a provisional hypothesis to the position of a strengthening doctrine, there is unusual interest in glancing over the progress of science and noting the actual steps by which the guess became theory, and the theory, doctrine. I shall therefore supplement the subject of nebular cosmogony with a concise historical sketch. This I think will be acceptable to the reader because cosmological science has now attained such a position that every intelligent person should possess some information respecting the exact views of Kant, Herschel and Laplace, the chief founders of this science as now accepted; while no adequate summary of their speculations — most especially those of Kant — is sufficiently accessible to the general reader.

CHAPTER I.

PRE-KANTIAN SPECULATIONS.

§ 1. GREEK PHILOSOPHERS.

THE familiar phenomena of whirlwinds, whirlpools and eddies seem to have suggested to reflecting minds in all ages, the possibility of some vortical theory for the explanation of the mechanism of the world. The diurnal and annual motions of the heavenly bodies were early submitted to an attempt at solution based successively upon Eudoxian, Hipparchian and Ptolemaic systems of cycles and epicycles. When the Copernican theory began to gain a foothold, it could no longer be doubted that the method of vortices was the method of the heavens. We now understand how the mutual actions of the numerous bodies in the material universe must result in a general and most intricate network of virtual revolutions about centres of gravity.

The doctrine of the rotation of the earth about an axis was taught by the Pythagorean Hicetas, probably as early as 500 B.C. It was also taught by his pupil Ecphantus, and by Heraclides, a pupil of Plato. The immobility of the sun and the orbital rotation of the earth were shown by Aristarchus of Samos as early as 281 B.C., to be suppositions accordant with facts of observation. The heliocentric theory was also taught, about 150 B.C., by Seleucus of Seleucia on the Tigris.* It is said also that Archimedes, in a work entitled *Psammites*, incul-

*Compare Whewell: *History of the Inductive Sciences*, Am. ed. i, 259; Delambre: *Astronomie Ancienne.*

cated the heliocentric theory. The sphericity of the earth was distinctly taught by Aristotle, who appealed for proof to the figure of the earth's shadow on the moon in eclipses.* The same idea was defended by Pliny.† These views seem to have been lost from knowledge for more than a thousand years. In 1356, Sir John Maundeville in his remarkable book of travels distinctly and intelligently revived the ancient idea.‡ In 1346, Nicolaus Cusanus wrote a work § in which the idea of the Greeks was scientifically defended. Thus was opened the way for Copernicus.‖

The introduction of the vortical conception into theories of the origin of things dates from an antiquity equally high. According to Anaxagoras of Clazomenæ, who was born about 500 B.C., the primitive condition of things was a heterogeneous commixture of substances which continued motionless and unorganized for an indefinite period. "Then the Mind began to work upon it, communicating to it motion and order.¶ The Mind first effected *a revolving motion* at a single point; but ever-increasing masses were gradually brought within the sphere of this motion, which is still incessantly extending farther and farther in the infinite realm of matter. As the first consequence of this revolving motion, the elementary contraries, fire and air, water and earth, were separated from each other. But a complete separation of dissimilar, and union of similar elements was far from being hereby attained, and it was necessary that within each of the

* Aristotle: *De Cœlo*, lib. ii. cap. xiv.

† Pliny: *Natural History*, ii, 65.

‡ *The Voiage and Travaile of Sir John Maundeville*, Kt., from the ed. of 1725. London, 1866. Chap. xvii, especially pp. 180–182.

§ *De Docta Ignorantia.*

‖ Aryabatta, an Indian astronomer, about 1322, A.D., and some of his countrymen, are said, however, to have taught the heliocentric doctrine. Draper: *Intellectual Development of Europe*, 145.

¶ Aristotle: *Physica*, viii, 1. Also, Diog. Laertius: *Lives.*

masses resulting from this first act, the same process should be repeated."* The views of Leucippus, and of Democritus, his disciple, promulgated about 430 B.C., present a closer relation to some aspects of the modern nebular theory. They maintained that space was eternally filled with atoms actuated by an eternal motion. The weight of the larger atoms forced them downward, while simultaneously the lighter ones were thrust upward. Mutual collisions produced lateral movements. Thus rotary motion was generated, "which extending farther and farther, occasioned the formation of worlds."† These views were extended by Epicurus and the Roman Lucretius,‡ though by them the lateral motion of the atoms was ascribed to choice — a conception of the animated nature of atoms which has been revived again and again, and especially in the seventeenth century by Gassendi and Leibnitz, and in the nineteenth century by Rosmini, Campanella, Bruno and Maupertuis.

§ 2. SPECULATIONS OF KEPLER.

The celebrated Kepler, about 1595, devised a curious hypothesis which made use of a vortical movement within the solar system. The conception of attraction and repulsion had come down from the epoch of Empedocles, by whom they were designated "love" and "hate;" but to the time of Kepler, no interaction between masses of matter had been distinctly recognized which was generically different from magnetism. When, therefore, Kepler projected a theory employing attraction and repulsion, he attributed these actions to cosmical magnetism. The sun was regarded by him as a great magnet revolving on an

* Ueberweg: *History of Philosophy*, i, 66.

† These views seem to have been quite definitely formulated by Leucippus, though they are generally attributed to Democritus. See Diogenes Laertius: *Lives*.

‡ Similar theories were long afterward entertained by Torricelli and Galileo.

axis whose position had been determined by the Divine Being.* The solar substance was immaterial, and sent forth radially an emanation of the same substance. These radiations rotated with the sun, and thus constituted a vortex. The whole surface of the sun was regarded as attractive, while the centre was repulsive. These two forces were everywhere in equilibrium, and hence a planet in any appointed position would be retained constantly at its mean distance, and would be carried around the sun in its vortex. The departure of the planetary paths from the circular form was explained by the supposition that each planet had one attractive side and one repulsive side, and that these were turned alternately toward the sun. Thus when the attractive side was turned toward the sun, the planet approached a perihelion, and when the opposite side was thus turned, the planet retired to its aphelion. The deviation of the orbital plane from the equatorial plane of the sun was accounted for by the supposition that the planet was furnished with certain "fibres" which, acting like a rudder against the sea of solar emanations, guided the body above or below the plane of the solar equator. Kepler, perceiving that the motion of the central sun must in time be diminished and exhausted, provided for its constant restoration by the perpetual care of the Creator, or by the assistance of a spirit designated for that employment.

A hypothesis more fanciful, and less in accord with the requirements of physical principles has not been offered in ancient or modern times.

§ 3. THE VORTICAL THEORY OF DESCARTES.

By far the ablest expositor of a vortical conception of the universe, without ostensible appeal to universal attrac-

*See Gregory: *Elements of Astronomy*, Sec. 10, Prop. 66; Delambre: *Astronomie du Moyen Age*.

tion, was Descartes.* He assumed, in brief, that infinite space is filled with infinite matter; that matter was originally in a chaotic, formless condition; that the cosmical bodies arose at first from vortical motions in the original mass. These bodies float in the rotating matter like a sleeping traveller in a ship at sea. Gravitation was not recognized, and all physical phenomena were explained by the laws of pressure and impulsion alone.

More particularly, Descartes supposed that all matter was in the beginning divided by God into particles of nearly equal size. They were small and were actuated by motions about their own centres. Not being in absolute contact, the universal substance was of the nature of a fluid. Groups of particles rotated also, about other centres remote from each other and thus established a corresponding number of vortices. Mutual friction reduced the particles to globules of various sizes, which he designates "particles of the second element." The matter of the "first element" consisted of minute parts rubbed from the corners of the globules. This matter rotated with great rapidity. Its abundance was more than sufficient to fill the interstices between the globules, and the surplus was collected at the centre of the vortex, in consequence of the retirement of the globules by virtue of their circular motion. The centrally accumulated fluid became a sun in the centre of each vortex. The sun had a rapid rotation about its axis, in common with the motion of the surrounding particles, and it also continually emitted some of its own substance which escaped radially with a

*His views are set forth comprehensively in the work entitled *Renati Descartes Principia Philosophiæ*, Amsterdam, 1644. Many editions of the complete works and of single works of Descartes have been published in Latin, French and German. Perhaps the best is Œuvres de Descartes, nouvelle édition précédé d'une introduction par Jules Simon, Paris, 1868. A summary of Descartes' vortical theory may be found in David Gregory's *Elements of Astronomy, Physical and Geometrical*, 1701. See, also, in the *Encyclopædia Britannica*, Art. Descartes.

spiral motion, through the narrow passages between the globules along the plane of the equator. These emanations, in their vortical movement carried the globules with them. But those nearest the centre moved with a higher velocity than those more remote, and must therefore have been smaller; for if of equal or greater mass, their greater momentum would have carried them off to the greater distances instead of the less. What is affirmed of any one vortex may be similarly affirmed of every vortex. But beyond a certain limit of distance from the centre, the globules are assumed to revolve with a quicker motion and to be of sizes as small as the lower ones. The orbit of Saturn marks this limit in the solar vortex.

Descartes posited also a "third matter," produced from the original particles. As the "first matter," resulting from friction, settles through the interstices between the rapidly revolving globules it becomes "twisted and channelled," and when it reaches the central orb it rests upon its surface like froth or foam, and constitutes spots, like those seen on the surface of the sun. In some cases, this foam dissolves into an ether surrounding the sun; but in others it accumulates in a thick and dense crust which weakens the expansive force of the central body.

Now, if we suppose the central sun of any vortex to become so "covered with spots" as to be materially "weakened" it would be gradually overcome by the vortical whirl of a neighboring sun. If now, this subjugated sun possess a feebler power of agitation, or have less solidity than the globules of the second element moving near the circumference of the subjugating vortex, but more than those nearer the centre of the vortex, then the subjugated sun will descend through the sujugating vortex until it arrives at a point where its solidity or aptitude to persevere in motion along a straight line, is equalled by that of the globules there surrounding it. In this situa-

tion it will float in equilibrium in the matter of the first element, and have no other motion than that which is imparted by the motion of the fluid in which it rests. It would thus become a planet revolving in a fixed orbit. It follows that the original space in which our present solar vortex exists contained seventeen or more vortices, the central bodies of which by becoming weakened, were subdued successively by the predominating vortex of our sun, and approached or retired to the positions in which their forces were in equilibrium with those of the surrounding globules. Some of these planetary centres, while yet they were suns, were of such mass that they exerted a more powerful influence than our sun, upon the vortices in their neighborhood; and thus certain minor vortices ranged themselves about Saturn, Jupiter and the earth, while all the others took at once, suitable positions in the solar vortex. Subsequently, the vortices of Saturn, Jupiter and the earth, yielding to the superior power of the sun, sank to their several places of equilibrium. The vortices became extinct, and the bodies moved as planets about the sun. The central bodies of still other vortices, if more than seventeen existed within the present solar vortex, passed away in right lines out of the solar vortex and became comets.

It follows from this theory that the denser bodies of our system are those more remote from the sun. For a similar reason the moon turns constantly the same side toward the earth, because the opposite side possesses the greatest density. The planets rotate on their axes because they were once lucid stars, the centres of vortices. Even now, the matter of the first element, collected at their centres, continues its gyratory motion and acts on the planets.

Finally, the centres of the planets must be subject to irregularities of the same meaning as those which characterize all natural things. All the bodies in the universe

are relatively contiguous to each other, and act upon each other. The motion of each is varied in innumerable ways. Hence, though all the planets approach a circular motion, in a common plane, none of them attain completely to these conditions.

This fanciful, arbitrary and really indefensible, but most ingenious theory commanded a wonderful degree of credence and respect, and even contended, on the continent, with the Newtonian theory of universal gravitation for acceptance as an adequate explanation of planetary phenomena.

§ 4. THE THEORY OF LEIBNITZ.*

1. *His Protogæa.*—The daring conception of a primitive molten world was clearly formed by Leibnitz. When once this thought was entertained as even a speculative doctrine, it was easy to push beyond to the conception of a world heated to volatilization, and a whole system in a state of incandescent vapor, or at least of dissociated particles in some such condition as Descartes had postulated. The mental process by which Leibnitz advanced toward the full acceptance of the vortical planetary theory, appears from some passages in his *Protogæa*,† which I here translate:

"§ II. It pleases the wise hands of nature that the globe of the earth, like all created things, should exist in a regular form; for God does not make things without method; and whatever is produced *per se* [by progress from earlier to later conditions. A. W.] either grows insensibly particle by particle,‡ or is fashioned by selec-

*Le grand Leibnitz lui-même s'amusa à faire, comme Descartes, de la terre un soleil éteint, un globe vitrifié, sur lequel les vapeurs, étant retombées de son refroidissement, formèrent des mers qui déposèrent ensuite les terrains calcaires.—Cuvier: *Discours sur les Révolutions de la Surface du Globe*, 45, Paris, 1828.

†Leibnitz: *Protogæa, sive de prima facie Telluris*, etc., first published entire in 1749. An abstract, however, was published in *Acta Eruditorum*, Leipzig, 1683, to which later contributions were continued till 1689.

‡*Insensibiliter aut concrescit per particulas.* Here we have the "principle of continuity" applied to the changes of the material world.

tion and conflict of the parts in effecting arrangements among themselves.* Hence the asperity of the mountains which roughen the face of the earth supervened on a primitive condition. And assuredly, if the earth could be conceived as liquid in the beginning, it should, of necessity, be also symmetrical. But it agrees with the general laws of bodies that solid substances should consolidate from liquid. This is evidenced from solids found inclosed in solids, certain layers and nuclei being very often rounded off at their angles and limits, and veins being frequently observed in rocks, and gems in stones. But also numerous relics of ancient things everywhere exist—plants and animals, and things artistically fashioned into a novel and stony similitude. It follows that what we now recognize as hard is a later formation; it must, therefore, have been originally fluid. Ultimately, fluidity itself results from internal motion, and, as it were, from some degree of heat.† This is shown by experiments. For even with undiminished heat, water becomes glass, while, on the contrary, corrosive fluids, strong through some hidden motion, are with difficulty congealed. But heat or internal motion is from *fire* or *light;* that is, *a pervading subtile spirit.* Thus, we arrive at the moving cause, whence, also, Sacred History derives the beginning of its cosmogony.

§ III. As far, therefore, as human knowledge is able to reach, either by ratiocination or by the teaching and tradition of the Sacred Scriptures, the first step in the formation of things is *the separation of light and darkness,* that is of things active and things passive; the second is, the *discrimination of things passive among themselves,* that is, the separation of things liquid from things dry; which two are distinguished, among things passive, according to their different power of resistance and degree of firmness. Thus bodies are variously transformed by fires and floods. Moreover, the things which we see opaque and dry were in the beginning ignited; then, after a time, being exhausted of their waters, the elements were separated, and, as we may believe, the present aspect of the world emerged. The facts according with these views certain priests of wisdom build into the form of a hypothesis, and explain more distinctly the method of separation. Namely, that certain vast globes of the universe were brought into existence, which then either shone by their

* *Aut pro sese disponentium delectu conflictuque tornatur.* Here is a distinct statement of the principle of "natural selection."

† *Porro ipsa fluiditas ab intestino est motu; et tanquam gradu caloris.* It is interesting to note here also a plain statement of the modern "mechanical theory of heat."

own light, according to the fashion of a fixed star or our own sun, or were projected from a sun of their own, their matter being subsequently boiled out and spumescent, and scoriæ issuing forth through fusion—a condition of matter perhaps analogous to that in the spots which dim the light of our sun, and which the ancients sometimes denied him, though they recognized a feeble obscuration, but which the optical instruments discovered in our age enable us to study. By excess, however, of accumulated material, the internal heat was overcome, and a cooled crust was formed surrounding the body. Thence came into existence the *dark star*, shining by reflected light, *like the planets*. That we inhabit such a Vulcan they either suppose or pretend to be established by that Mosaic separation of light and darkness. It is, indeed, believed by most people, and is also intimated by the sacred writers, that a store-house of fire is established in the interior of the earth, which at some time will again burst forth. This conjecture is confirmed by the vestiges of the primitive aspect of nature which still remain. For every scoria from fusion is a kind of glass. But the crust ought to resemble scoria, for this covered the fused matter of the globe as in a furnace of metal, and became hardened after fusion. That such, indeed, is the surface of our globe (for it is not given us to penetrate further) we actually experience. For all earths and stones return to glass by the agency of fire, and so much the more as they approach nearer the nature of a rude rock. Neither, meanwhile, would I deny that earthy and vitreous products may possibly be born from waters through transformations of a higher order; since it is evident that the waters are pregnant with various bodies, and that matter itself, everywhere similar to itself, is able *per se* to assume some certain form. Nor are there any ultimate unchangeable elements. But it is sufficient for us in this place, that by human art, through the efficient agency of fire, earthy matters become converted into glass. The great bones of the earth themselves, those naked rocks and eternal flints, what, since everything passes very nearly into glass, are they, unless consolidated from bodies formerly fused by that great primitive force which fire has hitherto exerted over facile matter? For this, surpassing by an enormous excess the power of our furnaces and their degree of duration, what wonder is it if it then produced results which men are unable to imitate, although art daily advances, and continually produces things new and unheard-of, yes, indeed, brings bodies fused by its own fire sometimes, to a high degree of hardness. When, therefore, all substances which are not

dissipated in vapors are at length fused, and, especially through the power of burning lenses, assume the nature of glass, it is easy to understand that glass is, as it were, the basis of the earth; and that its nature lies concealed under the masks of very many other bodies, its particles being variously corroded and elaborated, partly by solution and agitation of waters, partly by repeated elevations in vapor and distillations, until finally by the aid of salts added to the power of heat, stony hardness is reduced to mud suited for nourishing plants and animals, and is even reduced also, to a volatile nature. Meantime, by as much as anything in the earth is more nude and primitive, and approximated to the simple constitution of rocks, this the more persists in the fire, though it is fused by the highest heat, and finally vitrifies. For even a calcareous rock which resists our furnaces is reduced to glass by the speculum. Even as to sand, which is a large, and at the same time the simplest portion of the earth, and fills immense deserts and shores, and the bottom of the sea, and underlays the better soil with gravel, to what can it be referred on examination, more properly than to stones or translucent fluors, and, as it were, glass, by motion either in a state of fusion or by other means, reduced to small fragments?—a result also easily produced by fire if salts are present, and these have never been wanting from the beginning.

§ IV. From this genesis of things comes the origin of the salt sea observed to-day. For as things burned out attract moisture after cooling, whence oils are produced by chemists by means of lixiviation, so it appears, in the beginning of things, while our globe was yet incandescent and the opaque was not yet separated from the light, moisture, being expelled by fire, was not present in the atmosphere; but subsequently reproduced by a true process of distillation, it was again condensed into watery vapors through abatement of the heat; and when, by the cooling of the terrestrial surface, the mass became absorbed, it was finally returned in water, which bathing the face of the earth — the wide remains of the recent burning — received fixed salt in itself. Hence originated a sort of lixivium which flowed together in the sea. Indeed, from the analysis of plants, as has been noted from the observations of the Parisian Academicians, we have learned that two fixed salts remain in lixivia — the one alkaline, as the artisans express it, the name being derived from a plant which our people call *soda*, and the Arabes *cali*, the other marine, and more inclined to acid. Lastly, it may be supposed that the crust, contracting through cooling, as among metals

and other substances which by fusion become more porous, left bubbles, great according to the magnitude of the thing, that is, *cavities* under vast arches, inclosed in which was air or humor; that then also certain matters separated in layers, and that through variation of material and of temperature, masses subsided unequally, so that on every hand, disruptions occurred, the fragments being tilted in valley slopes, while the solider parts, like columns, held the highest place. Thus, therefore, mountains came into existence. The weight of the waters was added for preparing a basin in the still soft bottom. At length, either through weight of material or force of elastic vapors, the immense arches were broken; the humor in the cavities being expelled through the ruins or flowing spontaneously from the mountains, inundations followed, which thus again deposited sediments by intervals; and these hardening, and presently a similar cause returning, diverse strata were laid down one upon another, and so the face of the orb as yet tender, was many times renewed. At length, these causes becoming quiet and equilibrated, a more persistent state of things emerged. Whence now, a duplex origin of solid bodies is intelligible — one when they *solidify from fusion by fire*, the other when they *consolidate from solution in water*. It is not therefore to be supposed that stones arise from fusion alone. That this is most possible from the first mass and basis of the earth, I admit. Nor do I doubt that afterward, when liquid matter flowed over the surface of the earth, after the return of quiet, a great volume of materials was deposited from the eroded rubbish, of which some formed various kinds of earth, others hardened into rocks. Among these, diversified strata in regular order of superposition testify to the various recurrences and intervals of precipitation.

§ V. These things may perhaps be said without dissent concerning the cradle of our orb; and they contain the germs of a new science which might be designated *Natural Geography*; we venture, however, rather to suggest it than to construct it. For, although the sacred monuments of the divine oracles favor, we nevertheless defer judgment to those with whom is the right of interpretation. And although the vestiges of the ancient world are united in the present aspect of things, nevertheless, posterity will define everything more correctly, when the curiosity of mortals shall have proceeded so far as to describe the kinds of soil and the rocky strata extending through wide regions. But indeed, I do not impute all inequalities of the earth or the nature of the sea bottom to primitive solidification. It suffices to have deduced by general causes,

the skeleton itself, and, as it were, the bones of the earth's exterior, and the sum of its entire structure. For these seem to be the true sources, if you seek them, whence the immense cavity of the ocean has been derived, and the monstrous masses of the mountains, as for instance, * * * But I do not thus deny that the globe, being now solid, minor conflagrations and motions of the earth, and limited inundations,* and sedimentations from standing waters, have supervened, which have often taken possession of extensive tracts and transformed them; for of these the vestiges which still remain with us will presently be described. Nor is it doubtful that straits have been cut by incursions of the sea; that lands have been absorbed in the abyss or transformed into morasses; that shores have now been inundated, now uncovered; that lower places have been depressed, and narrows shut up by the ruins of mountains and the obstruction of the courses of the waters; that by turns lakes bursting through outlets violently opened, have excavated valleys for their discharge; that volcanic mountains have been opened and closed; that pumices have been spread far and wide, and the marks of conflagrations indelibly impressed. But what ought to be inferred from causes acting on a larger or smaller scale, posterity will sometime more easily determine, after the home of the human species shall have been more thoroughly explored." †

We find here very definitely enunciated, the germs of modern geological theory. A few of Leibnitz' contemporaries, more especially Steno, had already expressed a rudimentary conception of the agency of the sea in the deposition of fossil remains; but Leibnitz was the first to suggest the full extent of igneous action, and thus furnished the basis for the famous Plutonic theory which divided opinion a century later. More conservative, however, than the Plutonists, he united, as modern geology does, the principle of aqueous action with that of igneous action; and deserves to be counted one of the most philosophic and far-seeing among the founders of the science.

* *Privatas eluviones.*

† Most of the remainder of the Protogæa is devoted to accounts of caverns, metallic ores, gems and other minerals, with quite extended descriptions of fossil remains, the whole accompanied by eleven very good copperplates of illustrations.

Let us glance now more particularly at his cosmogonic views, which, so far as his own thought is concerned, were the logical outcome of his geology.

2. *His Planetogeny.*— The Cartesian theory commanded the general approval of Leibnitz; and his opinions were published as early as 1680,* in an essay on the causes of the celestial motions. He assumes that every body immersed in a fluid and moving in a curved line must be acted upon by the fluid itself. For a body moving in a curve tends continually to take the direction of a tangent, and would do so if there were nothing to restrain it. But nothing can restrain it unless contiguous to it; and in a fluid there is nothing contiguous except the fluid itself. It follows, therefore, that the fluid must possess the same motion as the body. This reasoning applies to the planets.

As the planets revolve about the sun according to the law of equal areas, the "ether or fluid orb of each planet" must move according to the same law. This will be the case if we conceive the fluid to consist of an infinitude of concentric circles, each revolving with a velocity inversely proportional to its distance from the sun. A circulation of this kind is termed harmonic. The actual motion of a planet is something more than this, since it moves with unequal velocity and at a varying distance from the sun. It must, therefore, be actuated also by a paracentric force, by virtue of which it approaches and recedes from the sun. But, in approaching the sun, its velocity is accelerated because then immersed in a fluid having a more rapid vortical movement, and in receding from the sun its velocity must be retarded until it accords with that of the zone of the fluid to which it has attained. "Consequently, the harmonic proportion holds not only in arcs of circles, but in describing any other curve," since the minute arc

* *Acta Eruditorum*, Leipzig, 1680.

described in each infinitesimal element of time is essentially identical, whatever the form of the curve.

The paracentric motion is composed of two factors; one is the tangential tendency which the planet must experience even when swimming in and with a fluid; the other is the sun's attraction, or rather the planet's gravity.* Since we know that each planet revolves in an ellipse with the sun in one focus, and with a velocity according to the law of equal areas; and since no law of circulation but the harmonic will afford the necessary conditions for this, it follows that we must seek a law of gravity, which, combined with the tangential tendency, will constitute such paracentric motion as in connection with the harmonic will carry the planet along the perimeter of an ellipse.† This law he demonstrates and enunciates as follows: "If a heavy body be carried in an ellipse, or any other conic section, with a harmonic circulation, and the centre, both of attraction and circulation, be in the focus of the ellipse, then the attractions or solicitations of gravity will be as the squares of the circulations directly, or as the squares of the radii or distances from the focus reciprocally." This, it will be observed, is precisely the law of gravitation previously announced by Newton and noticed in the *Acta Eruditorum* at Leipzig.

Leibnitz confesses that he is not prepared to indicate what motion of the ether it is which imparts that tendency called gravitation,‡ nor what causes the relation of different planets expressed by saying that the squares of their

* Such an expression is employed at the same time that Leibnitz opposes the Newtonian theory. This tendency here called attraction is (perhaps disingenuously) ascribed to some impulse received from the ambient fluid, as from a magnet.

† Some later Cartesians, as John Bernoulli, conceived a way of producing elliptic motion in a circular vortex.

‡ The successors of Leibnitz and Descartes thought they had discovered a means of constructing a vortex so as to produce a tendency of bodies to the centre.

periodic times are as the cubes of their mean distances from the sun.

One of the most obvious, as also most fatal, of the objections to these vortical theories, is the fact that in spite of the power of the fluid to carry the masses of the planets in a uniform direction, the tenuous comets pass through it unhindered and undeflected, and in all imaginable directions, and travel at the same time, like the planets, with velocities regulated by the law of equal areas.*

§ 5. THE VORTICAL THEORY OF SWEDENBORG.

In 1733–4, Emanuel Swedenborg, a Swedish philosopher, during a sojourn abroad, published a remarkable work on the Principles of Things, in which a vortical theory was set forth which in many respects was original and seems to be less amenable to certain objections than the theories of his predecessors.† The exposition of

*The reader may find these theories discussed in Gregory's *Astronomiæ Elementa* [or Elements of Astronomy, Physical and Geometrical, 1701]. Objections to the admission of an interplanetary fluid are extensively urged by Cotes in his *Preface* to Newton's *Principia*. On the conflict between Cartesianism and the Newtonian philosophy, see Whewell: *History of the Inductive Sciences*, Am. ed., i, 429–32.

†Emanuel Swedenborg: *Principia Rerum Naturalium*. Dresden and Leipzig, 1733–4, 3 vols. folio. [First Principles of Natural Things, being new attempts toward a Philosophical Explanation of the Elementary World.] This was produced in elegant style, with copious engravings, at the expense of the Duke of Brunswick. I have not seen the original work, nor is a translation of it included among the translations published by the "American Swedenborg Printing and Publishing Co.," New York, 1875; but through the kindness of Mr. T. F. Wright, one of the editors of the *New Jerusalem Magazine*, of Boston, I have been favored with the loan of a translation of the first volume, made by Rev. Augustus Clissold, M. A., and published in London, in 1846. As Swedenborg is principally known as a mystical writer on religious and theological subjects, it has been customary to pass by his scientific speculations as not having been based on any just and adequate apprehension of physical principles. Whether the charge be merited or not, we are interested in knowing what his views were. Moreover, Swedenborg did not retire from public and professional life to enter upon his course of theological meditation and study, until at the age of 57, which was eleven years after the publication of his *Principia*. During his professional career he was ranked as one of the most eminent scientists of

his theory is prolix and abstruse in an eminent degree; and a casual reader not possessed of a suitable cast of mind would pronounce it full of paradoxes and contradictions. Assuming, however, that the author must have possessed a logical apprehension of the things of which he wrote, I have educed and condensed the essence of his theory in the following statement.

The first cause is the infinite or unlimited. This gives existence to the first finite or limited. That which produces a limit is analogous to motion. The limit produced is a point, the essence of which is motion; but being without parts, this essence is not actual motion but only a conatus to it. From this first proceed extension, space, figure and succession or time. As in geometry a point generates a line, a line a surface, and a surface a solid, so here the conatus of the point tends toward lines, surfaces and solids. In other words, the universe is contained *in ovo* in the first natural point.

The motion toward which the conatus tends is circular, since the circle is the most perfect of all figures, and tendency to motion, impressed by the Infinite, must be tendency to the most perfect figure. "The most perfect figure of the motion above described must be the perpetually circular; that is to say, it must proceed from the centre to the periphery and from the periphery to the centre. * * * It must necessarily be of a spiral figure, which is the most perfect of all figures. In the spiral there is nothing but what partakes of a certain

Sweden, and of Europe, enjoying the society and patronage of the first officials, and of the princes and rulers of several countries. Especially was he known as a mathematician and mechanician. He wrote also on astronomy, physics, mineralogy and monetary science. He was offered the chair of pure mathematics in the University of Upsal, but declined; was a corresponding member of the Academy of Sciences of St. Petersburg, and one of the earliest members of the Royal Academy at Stockholm, where his portrait hangs near that of Linnæus, as one of the past presidents of the Academy.

* Clissold's translation, i, 63.

kind of circular form ; and nothing within it is put into motion but what takes a circular direction. The motion proceeds perpetually to a circle. The spiral motion may be said to be infinitely circular ; every motion around the centre is a circle ; its progression toward the periphery is circular [curvilinear?]; in a word, its figure is circular [curvilinear?] in all its dimensions and bearings. Perpetual circulation is the same as a perpetual spiral ; hence the most perfect figure of motion, as well in conatus as in act, can be conceived to be no other than the perpetual spiral, winding, as it were, from the centre to the periphery, and again from the periphery to the centre ; thus it is a perpetual reciprocation and spiral fluxion." *

But all this conatus and possibility of motion exists as yet only in a metaphysical sense. There is no actual motion. "Before anything can be produced, conatus must pass into act ; like what is formal into what is real ; and, consequently, the point must pass with its conatus into motion." † Motion, however, is the only medium by which anything new can be produced. Motion, itself, which is merely a quality and a mode, and nothing substantial, may yet exhibit something substantial, or the resemblance of what is so, provided there be anything substantial put into motion." ‡ Now, if an infinitely small particle be set in infinitely rapid motion by a spiral, it may be made to generate a line, a surface, or a solid, by suitable species of motion ; and thus a "simple finite or first substantial" would be originated. As the simple finite derives its existence from the motion in the primitive conatus, it will have an actual spiral motion. Thus the potential becomes actual. The simple finite is an epitome

* *Op. cit.* 63-4. Compare also, p. 82, speaking of finites. I leave it for others to explain the legitimacy of confounding circles and spirals.

† *Op. cit.*, 66.

‡ *Op. cit.*, 68.

of the world.* It fills space, but is minute beyond conception. It is endowed with figure. All its characters are exactly repeated in other finites. Possessing the same active force as the point, "it is able to finite and produce the subsequent and more compounded finites."† Thus compounds arise.

The motion in the finite is spiral and reciprocal, like that conative in the point. This spiral motion determines the position of two poles, and these assume the form of cones. With poles are coördinated "an equator, ecliptic meridians and other perpendicular circles."‡ The finite, from its inherited conatus, develops "a progressive motion of all the parts and spires." Moreover, since the centre of the spiral is not coincident with the centre of gravity of the corpuscle, the latter is rotated and constrains the corpuscle to a local motion. "Therefore, not only all the primitive force in the point, but that also which is derived into its sequents consists in this: that the motion, state or conatus in a point tends to a spiral figure. This motion, state and conatus cause an axial, and at the same time, a progressive motion. These together produce another or

* This account of the origin of a substantial particle seems to proceed on the principle of the infinitesimal calculus. Granted the infinitesimal matter, masses of matter are the necessary derivative. The infinitesimal finite seems to be assumed for a starting point in order to get as near as possible to a conception congeneric with that of the original point, which is only conatus. But between an atom of real matter and the absolute negation of matter in the point, is a chasm which does not seem to be bridged. Boscovich, who wrote in 1756 (*Theoria philosophiæ naturalis redacta ad unicam legem virium in natura existentium*), escaped this difficulty by assuming that the atom was not extended, though possessed of mass — a mere centre surrounded by spheres of repulsion and attraction. Sir William Thomson has propounded also, a dynamical theory of atoms (*On Vortex Atoms*, Proc. Roy. Soc. Edinboro', 18 Feb., 1867) in which the "vortex ring" of Helmholtz is made the type of an atomic ring formed of a primitive fluid perfectly incognizable except in this vortical mode of motion. The analogy of this to the vortical "first finite" of Swedenborg is apparent, though an important difference exists in the use of a primitive fluid by Sir W. Thomson.

† *Op. cit.*, 79.

‡ *Op. cit.*, 86.

a local motion, a motion in which consists the active power of finiting and compounding the sequents, and of modifying them throughout a lengthened series in the manner in which we perceive by our senses, the world at large to be modified." *

The world and the solar system are conceived as evolved through the continuance and enlargement of the processes mentioned above as in their incipiency. It would be too tedious for the reader to be conducted through the several hundred pages in which the author discourses of "second finites" and "third" and "fourth finites," "actives" and "substantials." Suffice it to say that the solar space is a grand vortex; † that it has grown through the concurrence of similar vortices; that no other force has been needed than the one at the solar centre, while this proceeded from the primitive point; ‡ that the sun is stated to rotate on an axis; "that the solar matter concentrated itself into a belt, zone or ring at the equator or rather ecliptic; that by attenuation of the ring it became disrupted; that upon the disruption, part of the matter collected into globes, and part subsided into the sun, forming solar spots; that the globes of solar matter were projected into space; that consequently they described a spiral orbit; that in proportion as the igneous matter thus projected receded from the sun, it gradually experienced refrigeration and consequent condensation; that hence followed the formation of the elements of ether, air, aqueous vapor, etc., until the planets finally reached their present orbits;" § that the process of system building extended to the stars, and that the Milky Way is the *axis* of the firmamental vortex.

* *Op. cit.*, 91–2.

† See, especially, Part III, ch. iv. *De chao universali solis et planetarum, deque separatione ejus in planetas et satellites.*

‡ *Op. cit.*, 203–8.

§ Rev. A Clissold's *Introduction*, p. lxxxi.

It will thus be seen that Swedenborg's theory begins with an immaterial point, like the monad of Leibnitz; that it therefore has no inertia to be overcome, but is gifted with an inherent force which finally flows out into actual motion and actual substance. Kepler also regarded the vortical medium as the immaterial emanation from the sun's body, but the planets which swam in it were material and were floated as in a material medium. According to Swedenborg, the planetary body is not passive, but possesses an inherent conatus to motion. It is difficult to perceive why Leibnitz, who posited self-moving monads, did not, like Swedenborg, avail himself of this mode of energy, and thus escape the difficulties imposed by the motion of inert bodies, and the presence of a medium which, by some mysterious selection, bore the planets in its vortex without affecting the comets.

The Swedenborgian theory is not regarded as completely set forth in the *Principia*. His later works are thought to be "fuller of philosophy." Mr. Wright, of the *New Jerusalem Magazine*, Boston, has pointed out passages which he thinks afford additional light.*

*These are *Divine Love and Wisdom*, beginning at No. 282, and *The True Christian Religion*, Nos. 76 and 78, especially No. 78. I take the liberty of quoting from a letter of Mr. Wright, what he regards as the deeper significance of these passages. "You will there notice that the idea is that creation is by the self-subsisting God; that His infinite love and wisdom demanded the universe; that its production was not by extension of the infinite, nor by the extension of nothing, but by the determination of the infinite into recipient forms produced by itself by degrees, each of which was the medium of creative energy to that next below; that this process terminated in matter; that this gradation was, is and always will be the vehicle of transmission of life from the Divine; that the preservation exemplifies the creation; that the production of forms of life on earth was through the production of their spiritual prototypes, when the time came for it in the process of development; thus, that the evolution was subject, at every point, to the creative process. This seems to us to be the whole view, of which that in the *Principia* is only a part." (*Letter* of February 24, 1880.)

§ 6. THE SPECULATIONS OF THOMAS WRIGHT.

The next prominent writer who put forth cosmogonic views worthy of comparison with later nebular theories was Thomas Wright, of Durham.* Unable personally to consult his writings, I am indebted to Kant for an intimation of the nature of Wright's speculations. In the Introduction to his *General History of Nature*, he says: "The First Part is chiefly occupied with a new system of world structure. Herr Wright, of Durham, whose treatise I first became acquainted with through the Hamburg'schen freien Urtheilen of the year 1751, gave me the first suggestion toward the contemplation of the fixed stars, not as a promiscuous assemblage without visible order, but as a system which sustains the greatest resemblance to a planetary system, so that, just as in the latter the planets are confined very nearly to a common plane, so also, the fixed stars arrange themselves as nearly as possible in their successive zones, upon a definite plane which must be regarded as extended through the whole heaven, and, by means of their densest aggregation in such plane, trace out that luminous belt known as the Milky Way."†

It appears that Wright entertained the conception of other firmamental systems, as well as of higher orders of systems successively ascending until the entire universe "revolved about the throne of God," as we have sometimes found the thought expressed in English literature. Kant refers to Wright again in connection with the question of the central body of the universe.‡ "What may be the constitution of this fundamental piece of the entire

* Thomas Wright: *An Original Theory, or New Hypothesis of the Universe*, London, 1750, 4to. An American edition, with Notes by Prof. C. S. Rafinesque, was published in 8vo at Philadelphia in 1837. No copy exists, however, in the library of the *Academy of Natural Sciences* at Philadelphia: nor have I been able to obtain a copy of the work in any edition.

† Kant's *Sämmtliche Werke*, i, 220.

‡ Kant's *Sämmtliche Werke*, i, 311.

creation, and what may be found upon it, we leave it to Herr Wright, of Durham, to determine. He, with fanatical enthusiasm, elevated in this happy spot, as on a throne of universal nature, a powerful being of the divine sort, possessed of spiritual attractive and repulsive powers, who draws to himself all virtues and repels all vices in the boundless sphere through which his activity spreads."

These are not weighty items for Kant to place on the credit side of his account with Wright; and it would appear that nebular theory is still less indebted than Kant to the bold English speculator.

CHAPTER II.

KANT'S GENERAL HISTORY OF NATURE.

No other thinker of modern times has been throughout his work so penetrated with the fundamental conceptions of physical science; no other has been able to hold with such firmness the balance between empirical and speculative ideas.—Prof. R. ADAMSON.

IMMANUEL KANT is the author who is generally regarded the first to outline the modern cosmogonic theory on a well apprehended basis of physical principles. The treatise* in which his views are set forth is, in many respects, remarkable. As it is known only in a general, and imperfect, way, to a large majority even of the well informed, I shall offer a somewhat extended digest of its positions. It will be noticed that, in accordance with the spirit and usages of his age, he entered quite freely upon themes which a strict judgment would set down as at best only collateral. But I shall endeavor to fairly reproduce the spirit of these parts, as well as those which are more strictly scientific. I am the better pleased to do this because Kant is not generally credited with entertaining some of the beliefs which are clearly reflected in the theological passages of this work.

§ 1. FIRMAMENTAL ORGANIZATION.

The author first directs attention to the familiar phenomena of the Milky Way. The diffused light of that

*Kant: *Allgemeine Naturgeschichte und Theorie des Himmels, oder Versuch von der Verfassung und dem mechanischen Ursprunge des ganzen Weltgebäudes, nach Newton'schen Grundsätzen abgehandelt.* Königsberg u. Leipzig, 1755. Kant's *Sämmtliche Werke*, Hartenstein edition, Leipzig, 1867, Bd. i, SS. 207-345.

belt he attributes, like Herschel after him, to the multitude of stars which lie in the line of vision; and the definiteness of the belt of light he compares to the "zodiac" within which the planets of our solar system move. All these stars he conceives to be travelling in orbits about the centre of the starry system, near which our sun is placed, or, perhaps, around more than one centre. These motions secure the stability of the system, and endow it with endless perpetuity. He regards the comets as original members of the solar system, and their high inclinations and erratic movements are compared with the more scattered fixed stars which lie more or less removed from the zone of the Milky Way. Such stars he calls "the comets among the suns." But why are not these movements among the stars observed by astronomers? He replies, with characteristic sagacity, that their immense distances render their changes of position imperceptible within a lifetime, and calculates that four thousand years would be required for one of the nearest to move over an arc of one degree. But he anticipates that the time will come when these movements will be discovered.* He remarks that the ancients noted stars in definite positions from which they have disappeared, and conjectures that they have simply changed their places. The excellence of instruments and the perfection of science give hope of fixing this conjecture on a certain basis. De la Hire had already remarked decided change in the stars of the Pleiades.

In the next place he directs attention to remarkable patches of light now known as nebulæ. Huygens had regarded them as openings in the firmament through which the glow of heaven shone. Maupertuis had consid-

* This anticipation has been fulfilled, but the stellar movements do not present that consentaneousness required by Kant's theory. They move in all directions, and not alone in paths parallel with the plane of the Milky Way. (See pp. 140–1.)

ered them heavenly bodies of vast dimensions. But Kant ventured to regard them as remote firmaments of stars whose immense distances reduced their light to a faint blended luminosity. To him they were only other Milky Ways, with motions and world systems akin to those presented by our firmament and solar system.

He dwells on these conceptions with warmth, and says: "They open to us an outlook upon the limitless field of creation, and afford an exhibition of the work of God, which is commensurate with the eternity of the divine Worker." * * * "The wisdom, the goodness, the power which here reveal themselves are infinite, and in the same measure productive and unresting; the plan of their revelation must, therefore, be precisely like them, infinite and boundless." *

The great philosopher falls into the error of regarding the comets as members of the solar system, and as generated by the same mechanical cause. He thinks a transition may be discovered between the planets and comets. The eccentricities of the planetary orbits increase, as a rule, from the nearer to Saturn — the remotest known in the time of Kant. The exceptions offered by Mercury and Mars may be attributed, he says, to their smaller mass, by which they received an excess of the centrifugal influence. Is it too much, then, to anticipate that planets which we may expect to discover beyond Saturn will possess a still higher eccentricity, and thus exhibit a graduation toward the class of cometary bodies? If this is likely, then not alone will there be revealed a transition toward comets in an increasing eccentricity of orbit, and thus a proof that the cause which imparted to both their orbital motions became, with increase of distance, feebler and less able to maintain the equilibrium of centripetal and centrifugal motions, but also less able to restrict the remoter bodies

*Sämmtliche Werke, 243.

to the common ecliptic plane which the comets have been permitted so singularly to abandon. We may, therefore, expect the discovery of planets beyond Saturn, whose eccentricity will diminish the gap which now exists between planets and comets, and which will be visible only in perihelion, a circumstance which, with their smaller dimensions and feebler light, has hitherto prevented their discovery. The last planet and the first comet may be regarded the same, and its eccentricity, we may believe, is so great that in its perihelion it intersects the orbit of the next interior planet which, perhaps, is Saturn itself.

§ 2. PLANETOGENY.

In the second part of this essay Kant approaches, first, the question of planetary origins and the causes of their motions. In contemplating the harmonious movements of the planets, two considerations impress us: First, so extended a system of mutual conformities seems to demonstrate a common cause. Second, the interplanetary spaces are so vast and so vacant that the admission of interacting influences seems impossible. Newton, says he, for this reason, could not admit the existence of any material cause acting across the intervals of the planetary framework, to impress common movements. He affirmed that the immediate hand of God had established the observed order without the intervention of the forces of nature. There must, however, be some conception which shall unite these two conflicting principles in a true system. The interplanetary spaces must have been formerly filled with a supply of efficient material for impressing the uniform motions of the heavenly bodies; and after gravitation had cleared those spaces, and all disseminated material had been gathered in separate masses, the planets must continue to move in unresisting space with the motion impressed upon them. I assume, he says, that all

the matter of the solar system, in the beginning of all things, existed dissolved into its elements, and filled the entire space of the system. Its existence is an outcome from the eternal idea of the Divine Mind. It was endowed with a tendency to form, through natural development, a more perfect constitution. But the difference in the kinds of elements induced motion in nature, and an organization of the fittest* out of chaos; so that the stagnation which must have resulted from universal identity of material was disturbed, and the chaos began to be organized at the points of the more powerfully attracting particles. These drew to themselves lighter particles, and the larger masses attracted the smaller, until at length a collection of bodies remained, animated by motions inherited from the past conditions.

But nature has other forces in store. The force of repulsion tends to the dissolution of matter. This force, during the process of descent of particles toward the centre of attraction, developed at times a transverse action, which deviated the particle from a direct line, and inaugurated a tendency to rotary motion. Thus came into existence the planetary and also the solar motions.† The beginning of planetary formation, however, is not to be sought alone in Newtonian gravitation. This would be too slow and feeble. We should rather say that the first organization took place through the accumulation of simple elements united by the customary laws of cohesion, until such masses were formed that the Newtonian attraction became sufficient to continually enlarge them by action from a distance.‡

Turning next to the densities of the planets, and the

*"Das Vornehmste."

† Our present knowledge of the invariability of the total quantity of motion within a system exposes a fallacy in this reasoning.

‡ This is another misapprehension, since gravity acts upon particles as well as masses.

relations of their masses, it is apparent, he says, that the condensation of the original matter must be proportioned to the distance of the particles from the attractive centre. Newton had believed that the variations in density were produced by the direct will of God. The lightest portions of the earth, for instance, must be distributed over the surface. Why then is the density of the sun less than that of the planets? Because the planets near the centre, and in fact all the planets, are composed of particles which, from their superior density have been drawn toward the centre, displacing the lighter particles or mingling with them in more than the normal proportion, while on the contrary, the body *at* the centre is composed of the general average of particles in respect to density, among which the lighter constitute the greater part.* In accordance with this view, concludes the author, "the moon is twice as dense as the earth, and the latter four times as dense as the sun; and the earth, according to all calculation, will be surpassed in density by the interior planets Venus and Mercury."† The increasing ratio of planetary masses as we recede from the sun is connected with the increasing diameters of the spheres of attraction of the planets, as their distances diminish severally the sun's influence. The excessive tenuity of the original stuff is shown by the fact that if all the planets were reduced to the density of our atmosphere, their matter would fill

*The passage (*Op. cit.*, p. 256) is involved and obscure. It is strange that the author did not perceive that the process of increasing condensation in the diffused mass could not be arrested at any given distance from the centre, but must be continued quite to the centre, and thus render the central body the densest of all.

†Modern astronomy has determined the following densities for these bodies: Sun, .255; Mercury, 1.21 (which is according to prediction); Venus, 1.03; Earth, 1.00; Moon, .607. Nevertheless, the remarkable coincidence remained, as pointed out by Buffon, that the mean density of all the planets is to the density of the sun as 640 to 650. But finally, the mean density of all the planets, according to present knowledge, and allowing for differences in the planetary masses, is to the density of the sun as 296 to 255 or as 640 to 552.

fourteen hundred thousand times the space of the earth; while this is thirty million times less than the entire space which the matter of the planets is supposed to have filled originally.

The gradually increasing eccentricity of the remoter planets is produced by the diminished centripetal force of the solar mass upon the descending particles, and their lower density and hence feebler power to overcome the resistance offered by the heavier particles to their direct descent toward the sun. These conditions attain their maximum in the region of the comets beyond the orbit of Saturn. To them are due also the high inclinations of the cometary orbits. As to the retrograde motions of certain comets, since they are in conflict with the theory, it is conjectured that with many of them the phenomenon may be *only an optical illusion*.

Satellites have come into existence through the operation, on a smaller scale, of the tendencies recognized in the organization of the planets. Axial rotations have been established by the primitive motions of the gathering particles. The synchronism of the moon's axial and orbital motions is a problem left for future solution.* The moon's rotation was probably more rapid once than at present. The same may be said of the rotation of the earth. The inclinations of the planetary axes may have been produced by an excess of momentum of particles descending upon one hemisphere; but more probably, perturbations have intervened to disturb the original positions of the axes. Moreover, the uplift of mountain masses unsymmetrically disposed must tend to change the position and inclination of the axis of a planet,† though this

*This seems a singular statement, since the author had already, in 1754, in a prize essay presented to the Academy of Sciences in Berlin, ascribed this synchronism to tidal action exerted by the earth.

†This is substantially the problem discussed by Rev. Samuel Haughton (*Proc. Roy. Soc.*, March 8, 1877, xxvi, 51–5, 55–63; December 20, 1877, xxvi, 534–

change is confined within limits. Such orographic disturbances belong to the earlier periods of planetary life, and Jupiter seems to be actually undergoing changes incident to the half-fluid and unsettled condition. "In such a state the surface can experience no repose. Upheavals and ruin reign upon it. The telescope itself assures us of this. The condition of this planet is perpetually changing."

The author next considers the origin of the rings of Saturn. A planet lying at the distance of Saturn must have many agreements with the neighboring comets, if, in fact, it has entered the planetary class as assumed, through the diminution of its eccentricity. Viewing the planet thus, there was a time when its great eccentricity brought it, in perihelion, into close proximity with the sun. The intense solar heat lifted its lighter material from the surface in the form of vapor. At a later period, with a moderated temperature, the vapors assumed the form of tails, and at length the cometary affinities of the planet were retained only in the permanent ring which surrounds it. In short, "Saturn has had a rotation upon its axis, and nothing more than this is necessary." * * * "I venture to declare that in all nature few things can be reduced to an origin so intelligible."* The velocity of rotation of the ring calculated from the periodic time of a satellite, gives the velocity of the equatorial portion of the planet at the time of the separation of the ring. Thus the planet's rotation is found to be 6 h. 23 m. 53 sec., and he leaves it for the future to test the result.†

Kant had knowledge of only a single ring around Saturn. But he calculated that the friction of outer and

46). See, also, G. H. Darwin's criticism (*Proc. Roy. Soc.*, March 14, 1878), and Prof. Haughton's reply (*Ib.*, May 23, 1878).

* *Op. cit.*, 275. Here is a distinct enunciation of the principle of annulation afterward employed by Laplace.

† It is given in recent works as 10 h. 14 m.

inner parts, due to difference of velocity must tend to the destruction of the ring. Instead of this event, however, it would separate into several concentric rings, each revolving in its own period.* The number of these rings could be computed if the degree of connection between the constituent particles were known. In any event, the equilibrium and stability of the rings is provided for. As to the condition of the matter of the rings, Kant continually speaks of particles and small parts (*Theilchen*), and clearly conveys the identical conception which has been enunciated by Peirce and Clerk-Maxwell in recent times. In a note of later date, he cites with satisfaction a record made by Cassini† half a century before, in which the conjecture is offered that "perhaps this ring may be *a swarm of small satellites*, which to an observer from Saturn may present somewhat the aspect of the Milky Way from the earth." Kant also cites with satisfaction the confirmation already furnished by Cassini, of his argument for the existence of *several* rings. He takes great pleasure, he says, in offering his theory of the rings, since he has the hope that it may be confirmed by new observations to be made with the improved telescope which he hears that Bradley has had placed at his disposal.

As to the possibility of rings about other planets, he shows by a simple calculation, based on the diameter of Jupiter, its period of rotation and the attractive force upon its surface, that a Jovian ring is impossible under present relations of these factors. He shows the same in reference to the earth.‡ But in former times, when the

*Compare the alleged tendency to stratification, stated on p. 119.

†*Memoires Acad. Sci.*, Paris, 1705.

‡In an editorial note is given the substance of an oral statement made by Kant concerning his theory in 1791. He thinks it has received much confirmation, especially through the light thrown upon it by a "Supplement" published by Herr Hofrath Lichtenberg, who suggests that in any aëriform "Urstoff" disseminated through space a high degree of elasticity must subsist, until through gravitational pressure it should be destroyed; after which the density

axial rotation of the earth was much more rapid, a ring may have existed. "What beauty of aspect for those who were created to inhabit the earth as a Paradise! How great a convenience for those on whom nature smiled from every side!" This ring must have consisted of watery vapor. Why may not its disruption through contact with a misdirected comet, or the process of cooling and condensation, have precipitated upon the earth that destructive flood, the Mosaic narrative of which has so puzzled all commentators?*

In this connection the Zodiacal Light is conjecturally referred to the same explanation as the Saturnian ring. It is regarded as a ring of particles surrounding the sun,† and lying nearly in the plane of his equator.

§ 3. THE COSMOS IN ITS TOTALITY.

The author proceeds now, in the seventh chapter of the Second Part, to a more particular consideration of the infinitude of the creation at large, both in respect to space and time. "The cosmical fabric, through its immeasurable magnitude and the endless variety and beauty which shine forth from it on all sides, impresses us with silent amazement." This feeling is enhanced by the discovery that this vast array of phenomena flows from the orderly and eternal working of a single general law. The stars are centres of other systems like our own. They are composed of the same elementary particles. Like the planets of our zodiac, they are arranged in a limited zone which we style the Milky Way. "The Milky Way is the zodiac

would become so increased that great heat would be developed which, in the larger bodies like the sun, would be accompanied by luminosity, but in the smaller, like the planets, would produce only an internal heat. Here is the contractional theory in the bud.

* This recalls William Whiston's grave conjecture that the Flood was caused by a blow from the tail of a comet.

† Poetically styled the "Halsschmuck der Sonne." This is precisely the modern view.

of the higher world orders." But even beyond the bounds of the system of the Milky Way, are other firmamental systems — other Milky Ways. We contemplate with amazement their faint figures pictured on the concave vault of heaven. The worlds of all these systems, to insure their stability, must necessarily possess motions analogous to those of our own system.* But has the succession of ever ascending world systems no end? It would be preposterous to contemplate the minute portion of space which we survey as the limit of the field of the divine activities. It is more suitable, more necessary to conceive the realm of the material creation as absolutely without bounds. We have good ground to conclude that the store of *created* matter† suffices for the production of a chain of cosmical order without limit. The basis matter itself is an immediate consequence of the divine existence, and must necessarily be so exhaustless and enduring as to extend the development of material organization over a plan of creation embracing all existence possible, without measure and without end. One might well conceive an endless succession of mutually disconnected world systems; but such a plan would not provide for the perpetuity of order; and unless the common principle of attraction extended through the entire universe of matter, there would be wanting that character of persistence which is the mark of the choice of God.‡ But a universal coördinating principle implies one common centre, and one vast central mass of matter. Here the process of creation began. From this middle point it has extended continually outward over the infinite chaotic waste of unorganized material atoms. I

*In this connection he uses the expression, *Das Licht welches nur eine eingedrückte Bewegung ist*, which is equivalent to the intimation that light is only "a mode of motion."

† *Der Vorrath des erschaffenen Naturstoffes.*

‡ *Die Beständigkeit die das Merkmal der Wohl Gottes ist.*

know of nothing which can lift the soul of man to a nobler amazement than the outlook over this boundless field of Almighty power. Worlds rise into being upon worlds, in endless progress ; and beyond the outer bounds of the widest realm of order, confusion and chaos forever contend on a field as limitless as if the work of creation had not already attained an endless development. Assign what diameter we will to the completed creation, we are always near the middle point; beyond the periphery of the sphere, over the infinite expanse, lie buried in the stillness of night, the germs of order awaiting the progress of eternity to be quickened into active life. So the process of cosmical organization extends itself. "Creation is not the work of a moment." Millions and mountain ranges of millions of ages will flow away and "the creation will never be complete. It was indeed once begun, but it will never end."

It is perhaps a daring conjecture that the cosmic productiveness of one part of immensity implies the comparative exhaustion of another part. But the resources of the universe are never diminished, for they are nothing else than the exercise of the divine omnipotence itself. The decay of worlds is but a part of the universal order which brings plants and animals and man himself to destruction, only to be succeeded by new organisms at some other point. "Whatever has origin and beginning has in itself the characteristic of its finite nature ; it must decay and come to an end." As man in course of time, retires from the stage on which he has acted his part, so worlds and systems, when their rôle is played, vanish from the scene. The infinitude of creation is wide enough to spare a world or a Milky Way as easily as a flower or an insect. "Meanwhile eternity is adorned with ever varying manifestations, because God remains active in the unceasing work of creation."

But when a system of worlds has fallen into disorder and decay, will no power be extended to effect a reorganization? We cannot long remain in doubt when we reflect that the ceaseless exhaustion of the motions of the planetary system must finally precipitate planets and comets together upon the body of the sun, and that then the solar heat must undergo an increase so immeasurable as to dissipate again the particles of the common mass through the distant regions of space from which they had been originally gathered together. Then must begin again the process of world organization whose completed cycle has been traced.

As a planetary system seems destined to decay, so the hosts of the system of the Milky Way must be conceived as wasting inevitably the forces by which they are animated. Countless suns will be precipitated upon the mighty central mass; but the tremendous shock will kindle an unimaginable intensity of glow, which must dissolve the bonds of matter, and expel its ultimate constituents again throughout the vast limits before engirt with the fiery girdle of the firmament. The soul of man in thinking of events of such stupendous magnitude sinks within him in deepest amazement. But the vastness of objects and events so enstamped with the characters of change and mutability leaves the soul still unsatisfied; "it feels a desire to know more intimately that Being whose intelligence, whose greatness, is the fountain of that light which, as if from a central source, illuminates the totality of nature." "Happy soul if amid the tumult of the elements and the ruin of nature, it can look down always from its lofty position, and see the current of desolation which brings ruin to all finite things sweep by, as it were, beneath its feet." "When, then, the fetters which hold us bound to the vanity of created existence, in the moment appointed for the transformation of our being shall have

fallen off, then will the undying spirit, freed from dependence on finite things, find the enjoyment of true happiness in communion with the eternal existence."

§ 4. OUR SUN AND OTHER SUNS.

The more particular constitution and activities of the sun result from the nature of the primitive particles and their mode of condensation. The lightest parts of the common matter which moves in the interplanetary spaces, from lack of adequate momentum are overcome by centripetal force and precipitated on the central body. But these parts are also the most energetic in the production of fire; and thus we see that through their addition to the central body it becomes a flaming orb. "On the contrary, the heavier and inefficient material, and the lack of fire-producing particles make of the planets only cold and dead clumps deprived of such a property." The sun must be surrounded by an atmosphere. "Without atmosphere no fire burns." Now, considering the great mass of the sun, to what a density must this atmosphere attain, and what intensity of combustion must it support. In this atmosphere ascend clouds of smoke consisting of commingled grosser and finer particles which, cooled in the higher regions, precipitate a rain of pitch and sulphur which afford the flames new aliment. This atmosphere, too, like that of the earth, is beaten by winds, and we may well imagine to what violence they must attain. But as is manifest, all flame devours its atmosphere, and without doubt the solar atmosphere must undergo a slow exhaustion. It is true, the interactions of the elements tend to replenish the atmosphere, that vast supplies must, for a long time, burst forth from concealed caverns in the solar structure, and that many substances, like saltpetre, are exceedingly productive of elastic gases, yet, though such causes must greatly prolong the solar heat, it must be

admitted the sun is in real danger of final extinction. The central body of our system will be quenched in eternal darkness. Undoubtedly, in the progress of decay, new-found material may sustain an occasional outburst of fiery energy, as with other suns in our firmament, which have been seen to assume a sudden luminosity and then to wane, yet our central orb must finally attain the exhausted and defunct condition which awaits all finite organizations. But its dead substance disseminated through space will plant chaos with the germs of new worlds.

"Let us contemplate in imagination, from a nearer standpoint, an object so extraordinary as a burning sun. At a glance we behold oceans of fire which raise their flames to heaven; raging storms of most fearful intensity which rolling over the shores submerge at times the elevated regions of the orb, and at times sink back upon their borders; burned-out rocks which from their flaming throats project their frightful tongues of fire, and whose submergence and emergence by the fluctuating fiery elements is the cause of the appearance and disappearance of the solar spots; dense vapors which choke the fire, and which, uplifted by the force of the wind, condense in dark clouds which storm down again in torrents of fiery rain, and as burning streams descending from the heights of the solid land, pour themselves into the flaming valleys, the crash of the elements, the refuse of burned-out matter and the disintegration of exhausted nature which through this terrible stage of desolation itself works out the beauty of the world and the uses of the created being." *

If all the stars are flaming suns, still more must the

* *Op. cit.*, 309-10. In connection with the supposed "solid land" of the sun, the author observes, in a note, that the formation of a world from material in a fluid state necessitates the development of inequalities of surface. After a crust begins to form, the confined gases would uplift it in places and accumulate in immense caverns, producing on the surface alternating elevations and valleys. This is an echo of Leibnitz.

central body of the Milky Way be such. Why then does it not become visible? The answer is obvious, when we consider that if that body were ten thousand times the bulk of our sun, and removed a hundred times as far as Sirius, it would appear no larger than that star. Future times may discover it, or at least the region in which it is located. I venture the conjecture that Sirius himself is the central body of the Milky Way. What may be the nature and condition of the central mass of the universe is a problem which, perhaps, involves us in rasher conjecture than a scientific theory allows; but I cannot admit with Wright that here the person of the Godhead is specially present. The divine presence is essentially and equally in every domain and place. I imagine, on the contrary, that the higher ranks of rational beings belong in regions remote from the universal centre. The density of the more central matter, whatever relations subsist between matter and spirit, must necessarily impart a greater degree of sluggishness and dulness to more central intelligences, while a keener insight and deeper penetration should characterize spiritual life connected with the lighter matter which pervades the region of more freshly organized cosmical existence.

§ 5. THE MECHANICAL CONSTITUTION OF THE WORLD.

The eighth chapter of the Second Part of the work offers some general reflections on the mechanical constitution of the world, and the inferences which may be legitimately deduced. "It is impossible," the author says, "to contemplate the fabric of the world without recognizing the admirable order of its arrangement, and the certain manifestation of the hand of God in the perfection of its correlations. Reason, when once it has considered and admired so much beauty and so much perfection, feels a just indignation at the dauntless folly which dares ascribe

all this to chance and a happy accident. It must be that the highest wisdom conceived the plan, and infinite power carried it into execution." He proceeds to defend the mechanical theory of the universe against the charge of "naturalism," and maintains that "the procedure of those naturalists who have delivered themselves of that kind of world wisdom must make solemn apologies at the bar of religion." One of the characteristic passages from this discussion is the following conclusion: "Nature, its general properties aside, is productive only of beautiful and perfect fruits, which display not alone harmony and perfection, but also harmonize perfectly with the whole compass of nature, with the needs of man and the honor of the divine attributes. It hence follows that nature's properties can possess no independent necessity, but that they must have their origin in a single Understanding as the ground and source of all being, in which they have been ordained in accordance with universal relations. All things which set forth reciprocal harmonies in nature must be bound together in a single existence on which they collectively depend. Thus there exists a Being of all beings, an infinite Understanding and a self-existent Wisdom, from which nature, in the whole aggregate of her correlations, derives existence. Further, it is not allowable to maintain that the activity of nature is prejudicial to the existence of a highest Being; the more perfect it is in its developments, the better its general laws contribute to order and harmony, the more conclusive is the demonstration of the Godhead from whom these relations are borrowed. His productiveness is no longer the operation of chance, or the consequence of accident; from him flows everything according to unalterable laws, which, therefore, must produce only what is fit, because they are only the reflection of a scheme infinitely wise, from which all disorder is banished. It is not the fortuitous con-

course of the atoms of Lucretius which has builded the world; implanted forces and laws whose source is the wisest Understanding, have been the unvarying cause of that order which can only flow from them, not by chance but by ordination."*

The author repeats the enumeration of the mechanical relations of the solar system, and maintains at length the improbability and unreasonableness of the view which ascribes them all to the immediate hand of God. Nevertheless, he says: "We rightly believe that fit arrangements, which tend toward a useful end, must have a wise understanding for their originator; and we are perfectly at liberty to think, if we choose, that since the natures of things recognize no other origin, their present and universal constitution must have a natural tendency to fit and mutually harmonious consequences." We need not hesitate to admit the operation of mechanical causes in nature, "since whatever proceeds from them is not the working of blind fate or irrational necessity, but is grounded finally in the highest wisdom, from which the constitution of nature borrows all its harmonies. This conclusion is perfectly correct: If in the constitution of the world order and beauty appear, then a Deity exists. But the other decision has not less foundation: If this order has proceeded from the general laws of nature, then all nature is necessarily a working of the highest wisdom."†

§ 6. DEDUCTIONS TOUCHING HABITABILITY AND UNITY IN THE SYSTEM OF WORLDS.

The Third Part of the treatise is devoted to a research concerning the influence which must be exerted on the spiritual natures of the different planetary inhabitants by the nature of the matter of which their bodies must be constituted. An unquestionable and intimate interaction

* *Op. cit.*, 315-6. † *Op. cit.*, 327.

exists between mind and body. The original constitution and the casual conditions of the body control, to a large extent, the operations of the spiritual faculties. Since, therefore, the planets near the sun are composed of heavier and more sluggish matter than the remoter planets, it must be that their inhabitants are endowed with less mental agility and a feebler power for thought and imagination. Jupiter seems indeed to exist in that formative condition which naturally precedes the reception of organic populations, but if his habitability is supposable, it seems strongly probable that his rational occupants, as well as lower animals and plants are formed of such light and active material elements as give an easier and more rapid activity to the discharge of their organic functions. The same may, with still greater probability, be conjectured of Saturn. As the mind is correlated to the body, the rational natures of these distant populations must exceed our own correspondingly, in expertness and comprehension. As all our apprehensions of external things are measured by the impression made by the universe upon the susceptibility of our material faculties of cognition, it may well be imagined that the remoter populations of our system have attained to knowledge which stretches hopelessly beyond the reach of terrestrial intelligences.

All material existence, however, is bound together in the common rational unity which finds its origin in the infinite Mind; and since even terrestrial intelligence is gifted with the power to seize hold on the chain of interconnection, it discovers, though perhaps faintly, the revelations of the divine perfections which nature displays to all rational beings. Man, perhaps, stands, in the ranks of created beings, between those who, on the one hand, are too pure to sin, and those, on the other, who are too unintelligent to sin. Man, perhaps, partakes exceptionally of the power to feel simultaneously the temptation to sin

and the aspiration to purity; but he feels that his immortal soul, gifted with being which even death cannot end, but can only change, is destined to an eternity of life unconfined to a single planet, but privileged to seek and attain the loftiest knowledge revealed in all the departments of the domain of Omniscience. This remarkable treatise concludes with the following paragraph:

"When, indeed, one's soul has been filled with contemplations like these, the view of the starry heavens on a cloudless night, confers a species of delight which only a noble susceptibility can appreciate. In the general stillness of nature and composure of thought, the mysterious intuitions of the undying spirit speak an unutterable language, and yield unformulated conceptions which it feels, indeed, but can never describe. If among the thinking creatures of this planet, beings exist so degraded that in the presence of all the inducements with which our exalted position invites them, they still hold themselves fast bound in the service of vanity, how ill-starred is this globe that it could nourish creatures so wretched! But how fortunate is it, on the other hand, that among all the most desirable conditions possible, a way is opened to attain bliss and exaltation which rise infinitely above all the preëminence conferred by the most advantageous organization of nature upon any one of the heavenly bodies."

§ 7. SYNOPSIS OF POINTS IN THE COSMOGONIC THEORY OF KANT.

1. *Points correctly taken, according to more recent opinion.*

(1.) The diffused galactic light results from the multitude of stars lying in the direction of the galaxy.

(2.) The stars must all be in motion, but their great distances demand thousands of years to render their motions clearly apparent. Future observation will demonstrate these motions.

(3.) The nebulæ are other firmaments. Though this opinion was entertained by the elder Herschel respecting resolvable nebulæ, recent opinion can hardly be said to be

formed concerning them; but of irresolvable nebulæ it denies the conclusion of Kant.

(4.) The interplanetary spaces must have been filled formerly with a supply of matter. All the matter of our system was formerly dissolved, and filled the entire space. Its tenuity was excessive.

(5.) Aggregation and organization began around certain centres of attraction.

(6.) The densities of the planets should diminish from the centre outward.

(7.) The greater masses of the exterior planets depend on the diminished power of the solar attraction in the remoter parts of the primitive stuff.

(8.) The synchronistic motions of the moon are due to ancient geal tides on that satellite. The solar and lunar tides are correspondingly diminishing the earth's rotary velocity.

(9.) The axial inclinations of the planets are probably due to perturbations.

(10.) The uplift of mountain axes must affect the position of the axis of rotation of a planet.

(11.) Jupiter exists in a half fluid and formative condition, not yet fitted for habitation.

(12.) The ring-condition results from axial rotation of incoherent matter.

(13.) Unequal velocities of outer and inner zones of a nebulous ring would result in separation into two or more rings. The ring of Saturn is probably multiple.

(14.) The Saturnian ring is a swarm of discrete particles or minute satellites.

(15.) Jupiter and the earth do not present, in our day, the physical conditions required for the existence of rings.

(16.) At a former period, when the rotation was much more rapid, the earth may have had a ring of watery vapor.

(17.) The zodiacal light is a ring of particles surrounding the sun.

(18.) The fixed stars are centres of other systems composed of the same substances as our sun.

(19.) Light is only a motion impressed.

(20.) The process of world making is continuous. The decay of worlds is but part of the universal order which returns in new worlds.

(21.) Whatever begins is finite and must come to an end.

(22.) Planets and comets must finally be precipitated upon the body of the sun; and the impact must generate enormous heat.

(23.) Similarly, the present order which pervades the starry system must come to an end.

(24.) The heat of the sun is destined to extinction.

(25.) Extremely violent actions are taking place upon the solar surface, and the solar flames rise to heaven.

(26.) The inhabitants of all worlds are bound together by a common rational apprehension of the system of nature.

2. *Points considered incorrectly taken.*

(1.) The fixed stars all move in orbits about a common centre.

(2.) The comets are original members of the solar system.

(3.) The eccentricities of the planetary orbits will be found to increase from the centre to the periphery of the system.

(4.) Rotary motions resulted from repulsive action exerted from centres of matter on descending particles.

(5.) The incipiency of aggregation resulted from cohesions rather than from Newtonian attraction.

(6.) The ring of Saturn results from intense solar heat exerted during perihelion, at a period when Saturn's ec-

centricity was very great. It is a transformed cometary tail.

(7.) The precipitation of planets and comets upon the sun would create sufficient heat to dissipate the matter of the system and reinaugurate the process of planetary evolution.

(8.) Mountainous inequalities in the crust of a solidifying world would result from the action of confined gases.

(9.) There must be a central body for the revolutions of the Milky Way; and this probably is Sirius.

CHAPTER III.

DR. LAMBERT AND SIR WILLIAM HERSCHEL.

§ 1. LAMBERT'S COSMOLOGICAL LETTERS.*

LAMBERT'S work was written in popular style, and for several years excited much attention, both on the continent and in Great Britain. But he followed quite closely in the tracks of Wright and Kant. Though his style was popular, he claimed, like Kant, to found his conjectures on substantial scientific data. His motor principle was universal attraction. Finding within our planetary system residual phenomena, especially as made known by Lalande in the systems of Jupiter and Saturn, which could not be referred to causes within the system, he concluded that they must be attributable to influences exerted from without. Unlike Kant, he regarded the comets as strangers, or at best but naturalized sojourners in the solar system. They constitute the material proof of the extension of the laws of attraction into the domain of the fixed stars. He felt, therefore, fully confirmed in an opinion which he had long entertained, "that our planetary system is only the system of satellites of another celestial body."† Accordingly, as each of the

*Johann Heinrich Lambert: *Kosmologische Briefe über die Einrichtung des Weltbaus*, Augsburg, 1761, 8vo. Part of these letters were translated by the author as *Lettres Cosmologiques* and published in the *Journal Helvétique de Neuchâtel*, 1763–4; an extract also, by Mérian under the title, *Système du Monde*, Bouillon, 1770, 8vo; also complete translation by d'Arquier, Amsterdam, 1801, 8vo. A portion, also, as *Cosmological Letters*, London, 1828. The substance of Dr. Lambert's speculations is given by Prof. S. Newcomb: *Popular Astronomy*, 465.

†Letter to Bockman, *Correspondance*, année 1773.

planets is, or may be, the centre of a system of revolving orbs, and the sun is the centre of the planetary system, so the planetary system with other similar systems, must revolve about some centre sufficiently massive to control its motions. Each star in the heavens is the sun of a planetary system; and in the clusters and constellations we see associated suns revolving probably with a common motion about their common centres. This vast assemblage of solar systems constitutes a system of a still higher order, which we know as the Milky Way, or Firmament. Still beyond this are other great systems or galaxies in endless succession, invisible to us only in consequence of their immense distances. The central masses, unlike Kant, he conceived to be dark and solid bodies, rendered invisible by their opacity.

This condensed statement indicates that Kant approached much more nearly than Lambert to the modern conception of a nebular theory of the planetary system.*

§ 2. SIR WILLIAM HERSCHEL'S RESEARCHES.†

1. *The Structure of the Heavens.*—Sir William Herschel found himself, through his own extraordinary ingenuity and energy, in possession of telescopes of power unparalleled in previous times. His attention was accordingly directed chiefly to the nature of the fixed stars and

* Johann Elert Bode, in an Introduction to Stellar Astronomy, entitled *Anleitung zur Kentniss des gestirnten Himmels*, Hamburg, circa 1767, reproduced the conceptions then current from the writings of Kant and Lambert. Many editions of this work have appeared — the seventh at Berlin, 1800.

† These researches are contained in the *Philosophical Transactions of the Royal Society of London*, from 1783 to 1818; but especially for the years 1784, 1785, 1791, 1795, 1811 and 1814. A digest of this work is given by Arago: *Analyse des Travaux de Sir William Herschel*, in Annuaire du Bureau des Longitudes; and a brief account is contained in Newcomb's Popular Astronomy, 465-74 and 495. Compare, also, Sir John F. W. Herschel: *Observations of Nebulæ and Clusters of Stars, Made at Slough with a Twenty-feet Reflector, between the Years 1825 and 1833*, Philosophical Transactions, Nov. 21, 1833. Prof. Holden's "Life" of Sir William Herschel I have not seen.

the constitution of the stellar and nebular system. In 1784* he announced that the sun must be included in the great stratum of the Milky Way. He explained his method of gauging the depths of the firmament, based on the assumption that the stars are somewhat uniformly distributed through space. On such an assumption the number of stars exhibited within the field of his telescope would be an indication of the depth of the firmament in the direction of the line of sight. He concluded, as Kant had already done, that the greatest dimension of the firmament is in the direction of the Milky Way. Our firmament may be regarded as a flattened spheroidal assemblage of stars, having our sun near the centre, but not entirely symmetrical in its contour. In the direction of the galaxy the depth of the firmament, with the consequent number of stars lying in the line of sight, renders many of the individual stars undistinguishable, and produces that cloud-like diffused luminosity characteristic of the galactic belt. On the sides, however, the diffused light is wanting, the stars are less numerous, and the depth of the firmament must, therefore, be considered less.

In the following year appeared one of Herschel's most important papers on the constitution of the visible universe.† He presents a "theoretical view" in the following words: "Let us then suppose numberless stars of various sizes scattered over an indefinite portion of space in such a manner as to be almost equally distributed throughout the whole. The laws of attraction, which no doubt extend to the remotest regions of fixed stars, will operate in such a manner as most probably to produce the following remarkable effects," which he styles "the formation of nebulæ"—an expression which reflects the

* *Of Some Observations Tending to Investigate the Constitution of the Heavens*, Phil. Trans., vol. lxxiv, 437.

† *On the Construction of the Heavens*, Phil. Trans., 1785, vol. lxxv, p. 213.

opinion then held by him, that all the nebulæ are clusters of stars like our own firmament, but all external to it, and in many cases "unresolvable" only in consequence of their enormous distances. He conceives that forms like the following must result: *Form* 1. A large star draws surrounding smaller ones toward it, and a cluster with a globular figure results. *Form* 2. A few stars, closer together than the average, constitute a central attractive group. From this process a great variety of shapes might result. *Form* 3. Produced by the "composition and repeated conjunction of both the foregoing forms." The result would be "long-extended, regular or crooked rows, hooks or branches." *Form* 4. Still more extensive combinations, when, at the same time that a cluster of stars is forming in one part of space, there may be another collecting in a different, but perhaps not far distant quarter, which may occasion a mutual approach toward their common centre of gravity."* *Form* 5. "As a natural consequence of the former cases, there will be formed great cavities or vacancies by the retreat of the stars toward various centres which attract them."

He then replies to certain objections which might be offered against such conceptions. Such an arrangement, it might be said, tends to "general destruction by the shock of one star's falling on another." He replies: 1. The Creator has the power to avert such destruction, and conserve the celestial order by some method not known to us. 2. "The indefinite extent of the sidereal heavens must produce a balance that will effectually secure all the great parts of the whole from approaching to each other." The stars may also have had an original force of projection, and this would secure perpetuity to each cluster "at least for millions of ages." "Besides, we ought, per-

*These specifications are similar to those presented in the present work, Part I, ch. ii, except that they are applied to the congregation of stars instead of the aggregation of nebulous matter.

haps, to consider such clusters and the destruction of now and then a star, in some thousands of ages, as perhaps the very means by which the whole is preserved and renewed. These clusters may be the laboratories of the universe, if I may so express myself, wherein the most salutary remedies for the decay of the whole are prepared."

Herschel then presents further details of results of star gauging, with confirmations of his former conclusions respecting our star cluster.

2. *Nebular Studies.*—The unequal distribution of the nebulæ receives his attention. Those regions in which the nebulæ are most evenly scattered possess "a certain air of youth and vigor." The stellar bodies have not yet had sufficient time to withdraw themselves from wide spaces in their process of general aggregation. The nebular forms of the first and second class "probably owe their origin to what may be called the decay of a great compound nebula of the third class; and the subdivisions which have happened to them in length of time have occasioned all the small nebulæ which spring from them to lie in a certain range, according as they are detached from the primary one. In like manner, our system, after numbers of ages, may very probably become divided so as to give rise to a stratum of two or three hundred nebulæ; for it would not be difficult to point out so many beginning or gathering clusters in it." Some parts of our firmament indeed, begin to show the "ravages of time," for the stellar bodies have been almost completely withdrawn from them. One of these remarkable "openings in the heavens" exists in the Scorpion. Other parts present a wonderful degree of "purity or clearness," and this is the general aspect of the sky "when we look out of our stratum at the sides."

In this connection he enumerates several other Milky Ways or firmaments, some of which are supposed to be

much larger than our own, and one of which presents the aspect of a ring of stars. "Planetary nebulæ" are particularly noticed. They present, unlike ordinary nebulæ, a uniform brightness from side to side. Their "light, however, seems to be of a starry nature, which suffers not nearly so much as the planetary discs are known to do when much magnified." Their light is uniform and vivid. Their diameters are too small for nebulæ; and their brightness is too persistent under high powers, to be of a planetary character, while it is not intense enough for fixed stars. They are probably nebulæ; "but then they must consist of stars that are compressed and accumulated in the highest degree. If it were not perhaps too hazardous to pursue a former surmise of a renewal in what I figuratively called the laboratories of the universe, the stars forming these extraordinary nebulæ, by some decay or waste of nature being no longer fit for their former purposes, and having their projectile forces, if any such they had, retarded in each other's atmosphere, may rush at last, together, and either in succession, or by one general and tremendous shock, unite into a new body. Perhaps the extraordinary and sudden blaze of a new star in Cassiopœia's Chair, in 1572, might possibly be of such a nature."*

Hitherto, Herschel had considered all the nebulæ as merely clusters of stars. Some of them had been actually resolved into points of light, and their resolvability seemed to bear a relation to the telescopic power employed. It was perfectly natural, therefore, to conclude that all would show resolvability if instruments sufficiently powerful could be brought into use. But in 1791† he began to

* Herschel's conception of the form of our firmament is illustrated in Plate viii of the volume of *Transactions* last cited. These figures are reproduced in Newcomb's *Popular Astronomy*, pp. 469 and 481. For a popular and brilliant exposition of Herschel's views, see Prof. J. P. Nichol: *Views of the Architecture of the Heavens*, Amer. ed., 1842.

† *On Nebulous Stars Properly So-called*. Phil. Trans., 1791.

suspect that certain cases of diffused luminosity could not arise from the blended light of numerous distant suns. The "nebulous stars," now first observed, present a bright central body surrounded by a faint light cloud. Now if this envelope consists of stars, they must be either too small to be regarded as stars, properly speaking, since while the central star is perfectly distinct they are indistinguishable, or otherwise, the central star must attain a magnitude which surpasses credence. This subject, even while researches of diverse nature occupied his time,* seems to have been kept before his attention. In 1811 he presented one of the most important papers of the remarkable series which resulted from his highly original investigations.† He here formally announces a gradual change of opinion in regard to the resolvability of some of the nebulæ. The most primitive nebular condition is represented, he thinks, by the simple diffused nebulosities, of which he has determined the positions of fifty-two. The brighter portions he regards as more dense, and the central condensation is due to the action of gravity. Some nebulæ seem to have more than one centre of attraction; and some, it may be, are even undergoing a process of disintegration. The spheroidal forms would naturally result from the action of a central attractive force. There are many in which the central brightness indicates the

* In 1795 he communicated a paper *On the Construction of the Sun and Fixed Stars*, in which he recorded the opinion that many of the stars are habitable, since some are too close to admit of planetary orbits, and that if not habitable in the character of suns "many stars, unless we would make them mere useless brilliant points, may themselves be lucid planets, perhaps unattended by satellites." In 1805 he discussed *The Direction and Velocity of the Motion of the Sun and Solar System*. (See also Phil. Trans., 1783, *On the Proper Motion of the Sun and Solar System*.) The conclusion of his researches on this point is that the sun is moving toward the constellation Hercules. In 1806 he read a paper *On the Quantity and Velocity of the Solar Motion*.

† *Astronomical observations relating to the construction of the heavens, arranged for the purpose of a critical examination, the result of which appears to throw some new light upon the organization of the celestial bodies.*

seat of principal attraction. Some even have a distinct central nucleus. The various degrees of condensation are supposed to take place successively in the same nebula.

The appearance of certain very regular nebulæ with extensive branches suggests various queries. Do not the branches connected with a nucleus resemble the zodiacal light connected with our sun? May not portions of branches collect into a planetary form and *revolve* around the central nucleus [of the nebula], having themselves a rotary motion in consequence of the inequality and irregular position of the different branches? Seven nebulæ are mentioned which seem to have approached very near to final condensation. The spheroidal form which prevails among nebulæ is something from which a rotation on their axes may be inferred.

That nebulæ do really undergo successive changes, Herschel concludes not only from a comparison of different nebulæ with each other, but from a comparison of his own observations made on the nebula of Orion at this time, with those which he himself made thirty-seven years before. This nebula he thinks is certainly nearer than the stars of the seventh or eighth magnitude, and it may possibly not be more distant than those of the third.

He suggests, at this time, the following gradation of nebular existences: 1. Diffused nebulosity, invisible until partially condensed. 2. Planetary nebulæ, with uniform light. 3. Stellar nebulæ, having a bright central nucleus. 4. A complete star, all the nebulous matter being condensed.

In 1814 Herschel's views had become still more clearly defined.* He shows that clusters of stars are gravitating together like nebulous matter. Some stars are attracting

* *Astronomical observations relating to the sidereal part of the heavens, and its connection with the nebulous part; arranged for the purpose of a critical examination.* Phil. Trans., 1814, p. 248.

patches of nebulous matter to themselves. Stars and nebulæ seem to be drawn together by mutual attraction. By additions of matter there may be thus a real growth of stars. He mentions one hundred and fifty instances in which clusters of stars, by being more dense toward the centre, manifest a tendency like that in nebulæ. He suggests now, the following gradation in nebular development: 1. Globular nebula. 2. Nebula with nucleus. 3. Nebulous star. 4. Distinct star surrounded by a nebulosity. 5. The perfect simple star.

In 1817 and 1818* Herschel returned to the work of sounding the depths of the firmament, basing his conclusions on the assumption that the distances of the stars are on the whole inversely proportional to their brightness. He concludes, as the result of these renewed researches, that his former determinations do not require material alteration, and that little further knowledge is attainable in reference to the form and depth of our firmament, especially in the direction of the Milky Way.†

* *Astronomical observations and experiments tending to investigate the local arrangement of the celestial bodies in space and to determine the extent and condition of the Milky Way.* Phil. Trans., 1817, p. 302. *Astronomical observations and experiments selected for the purpose of ascertaining the relative distances of clusters of stars, and of investigating how far the power of our telescopes may be expected to reach into space when directed to ambiguous celestial objects*, Phil. Trans., 1818.

† Sir John Herschel, in communicating to the Royal Society, *Observations of nebulæ and clusters of stars made at Slough with a twenty-feet reflector, between the years 1825 and 1833* (Phil. Trans., Nov. 21, 1833) supplies an appendix to his father's researches. He transmits a catalogue of 2,500 nebulæ and clusters, of which 2,000 had been previously reported by his father. The most remarkable nebulæ were accompanied by sketches. "Among these are represented some very extraordinary objects which have not hitherto sufficiently engaged the attention of astronomers, and many of which possess a symmetry of parts and a unity of design strongly marking them as systems of definite nature, each complete in itself, subservient to some distinct, though to us inscrutable purpose."

CHAPTER IV.

LAPLACE'S SYSTEM OF THE WORLD.*

France possesses an immortal work, *L'Exposition du Système du Monde*, in which the author has combined the results of the highest astronomical and mathematical labors, and presented them to his readers free from all processes of demonstration. The structure of the heavens is here reduced to the simple solution of a great problem in mechanics; yet Laplace's work has never yet been accused of incompleteness and want of profundity.—HUMBOLDT.

§ 1. PRELIMINARY VIEWS ON NEBULÆ AND GENERAL PHYSICAL ASTRONOMY.

THE purpose of this work is to present in popular style the general results of astronomical research. It describes the apparent movements of the heavenly bodies and their real movements, proceeding thence to an exposition of the mechanical laws of their movements, and of the theory of universal gravitation, and of its operation in the forms and interactions of the planetary masses. The last book is devoted to an epitome of the history of astronomy, in the last chapter of which the author presents some general reflections, and records some remarkable anticipations of future discoveries.

He expresses the opinion that some of the other planets may be the abodes of animals and plants analogous to those which exist upon the earth; but the great diversities of temperature must necessitate a remarkable diversity of organization. The physical relations which

* Pierre le Marquis de Laplace: *Exposition du Système du Monde*, 5*me ed. revue et augmentée par l'auteur*. Paris, 1824. 4to, pp. 419. The original edition was published in two vols. 8vo, Paris, 1796, and the sixth edition, containing a eulogy by Baron Fourier, in 4to, 1835, eight years after Laplace's death. An English translation exists.

exist among the planets shed much light upon their origin. The astonishing number of uniformities enumerated could not arise from any irregular causes. Subjecting the question to computation, it appears that the probability is more than two hundred trillions to one that these harmonies are not the result of chance. "It is necessary, therefore, to assume that one primitive cause has directed all the planetary movements." Another remarkable fact is the small eccentricity of the planetary orbits. There is no intermedium between the planets and the comets in this respect. "What is that primitive cause? I shall offer a hypothesis in the note at the end of this work, which appears to me to result, *with great probability*, from the preceding phenomena; but I present it with the diffidence which ought to inspire everything which is not the result of observation or of calculation."

Before proceeding to reproduce the substance of the note, I think it proper to follow the author in some of his general considerations, since, as will appear, they are connected with his hypothesis, although not made to constitute a part of it. Some of the phenomena of our system Newton confessed his inability to refer to the principle of gravitation. Such were the uniformity in the directions of planetary movements, the nearly circular forms of the orbits, and their remarkable conformity to one plane. These adjustments Newton, in his general scholium,* pronounces to be "the work of an intelligent and all-powerful Being." "But," asks Laplace, "might not these arrangements be an effect of the laws of motion; and might not the supreme intelligence which Newton invoked have caused them to depend on a more

*Laplace in a note says; "This scholium is not found in the first edition of Newton's work. It appears that Newton to that time was devoted exclusively to the mathematical sciences which, unhappily for them and for his own fame, he too soon abandoned."

general phenomenon? Such is, according to our conjectures, that of a nebulous matter dispersed in masses through the immensity of the heavens. Is it possible then to affirm that the conservation of the planetary system enters into the views of the author of nature? The mutual attraction of the bodies of this system cannot alter its stability, as Newton himself demonstrated; but there may be in celestial space *some other fluid than light;* its resistance, and the diminution which its emission causes in the mass of the sun, must at length destroy the arrangement of the planets, and, to maintain it, a reconstitution would undoubtedly become necessary. But do not the numerous species of extinct animals whose organization Mr. Cuvier has determined with such rare sagacity, in the numerous fossil bones which he has described, indicate a tendency in nature to change even those things which appear most permanent? The grandeur and importance of the solar system ought not to constitute an exception to this general law, for they exist only relatively to our insignificance, and this system, vast as it seems, is only an insensible point in the universe. Glance over the history of the progress of the human mind and its errors, and we see there final causes continually retreating before the bounds of human knowledge. Those causes which Newton removed to the limits of the solar system were, even in his time, located in the atmosphere for the explanation of meteors. They are nothing, then, in the eyes of the philosopher, but the expression of our ignorance of true causes."* Casting our eyes be-

* This passage shows that by "final causes" Laplace understood that dernier resort to which we all come at last — the most learned philosopher as well as the mediæval religionist — where actual knowledge can furnish no further explanation, and judgment and reason together fall back on an inscrutable world-making agency. "Final causes" — last causes — are simply the antithesis of known and explicable causes — that is, explicable as to their *modes of operation.* Now, in this sense, it is obviously unsafe to declare at any stage in the extension of our knowledge, that mind will make no further advance, and that all

yond the limits of the solar system, the changes observed in the color and brightness of certain stars show that the principle of permanence cannot be of universal application. The temporary star described by Tycho Brahe convinces us that in the depths of space revolutions occur which surpass beyond computation all which take place on the surface of the earth. As this star did not cease to exist after it became invisible, we are taught that other equally considerable, but dark and invisible, bodies, may exist in number perhaps equal to the number of the stars. The heavenly bodies are undoubtedly assembled in groups. The group to which our sun belongs seems to encircle the heavens as a Milky Way. Like the Milky Way, many of the nebulæ are probably assemblages of stars which to a beholder from their interiors would seem like other galaxies.

beyond is simply the product of "final causation"— that is, of divine causation. If this were the only conception of final cause, we should truly be compelled to abandon the search for it; and yet every intelligent person would feel constrained to admit that somewhere is an ultimate limit to the activity of secondary causation (physical antecedence and sequence) and a real beginning proceeding out of some activity which is supernatural.

But the term "final cause" has a more legitimate signification which furnishes something worth contending for. It implies, that in the exertion of that primitive supernatural causation there must have been some *purpose* present. It implies, therefore, that in the endless series of events which flow from that primitive causal act that primitive purpose is ever unfolding and ever present. It does not imply that in any specific result finite intelligence can certainly eliminate the specific divine purpose; but it does imply that in every specific result there is *some* divine purpose.

If, as modern physics tend to conclude, the physical forces are only the manifestations of a supreme will, exerted according to a predetermined method, then each specific and individual result will associate with it directly, the necessary conception of purpose, just as that conception is always inseparable from primitive causation.

It is only a superficial and unsatisfactory science which contents itself with the observation and collocation of mere phenomena, and the determination of the methods according to which they emerge into existence. The human mind demands causes — and not alone physical causes or mere uniform antecedents — but real ultimate causes, "metaphysical causes." I maintain, therefore, that every normally active intellect tends toward metaphysical conceptions of material phenomena. (See an article by the present writer on *The Metaphysics of Science*, in North American Review, Jan., 1880, also, *Sparks from a Geologist's Hammer*, pp. 358-85.)

Herschel has followed the progressive changes in nebulæ, as we trace the life history of a tree, by observation of successive states contemporaneously existing in different trees. His classification of nebulæ is then cited,* and particular attention is directed to the stellar nebulæ in which a well marked nucleus, or several of them, has already come into existence. The atmosphere of each nucleus seems to be condensing upon the centre. When the matter condenses uniformly, a planetary nebula results. The phenomena indicate with great probability a progressive transformation into stars, and imply that existing stars were at a former time nebulæ. "Thus we descend through the process of condensation of nebulous matter to the consideration of the sun surrounded at a former time by a vast atmosphere, a conception to which I have already been led by a consideration of planetary phenomena, as will appear in the note before referred to. A coincidence so remarkable in pursuing opposite courses gives to the existence of this former condition of the sun a high degree of probability."†

"In connecting the formation of comets with that of nebulæ, we may regard them as small nebulæ wandering from solar system to solar system, and formed by the condensation of nebulous matter dispersed with so great profusion through the universe. *Comets would thus be, in relation to our system, what aërolites are in relation to the earth, to which they are strangers.*" * * * "This

*See above, p. 604.

† It is often alleged by the opponents of the nebular theory that its author — meaning Laplace — placed a low estimate on its importance and probability, and therefore hid it away in a note at the end of the volume. But such expressions as that above quoted, and others hereafter to be quoted, indicate that Laplace regarded his hypothesis as possessing great strength. Moreover, many of the accessory facts and reasonings are embodied in the leading discussions of his work. More than a quarter of a century after the publication of the work, the author referred to this theory with a degree of complacency which showed that years had ripened the conviction of its tenability and value.—*Mécanique Céleste*, tom. v, 346.

hypothesis explains in a happy manner the enlargement undergone by the heads and tails of comets in their approach to the sun; the extreme rarity of their tails, which, notwithstanding their immense thickness, do not sensibly diminish the light of the stars seen through them; the varied directions of the motions of comets, and the high eccentricity of their orbits."

The movements revealed in the solar system are exceedingly complicated. Like the planets, however, the stars are also in motion. The sun describes an epicycloidal orbit around the centre of gravity of the universe. Ages must be demanded to enable us to determine precisely the movements of the sun and the other stars: but observation has already shown that the stars have real motions, while some of the double stars are proved to possess orbital movements about a common centre of gravity; and even the nebulæ, especially that in Orion, have been observed in progress of change. Such phenomena will present to the astronomy of the future its principal problems.

§ 2. HYPOTHESIS TOUCHING THE GENESIS OF THE SOLAR SYSTEM.

We come now to the contents of the celebrated Note. Its scope embraces only the solar system, but we have seen that the grounds of the hypothesis are supplied in the facts of positive astronomy in all its range. Buffon attempted to explain the origin and phenomena of the solar system by supposing that a comet had struck the sun and detached a torrent of matter which gathered in planetary globes more or less removed, and in course of time became cold and opaque. While this hypothesis explains many of the phenomena cited, it does not explain why the planet rotates in the same direction as its orbital motion, nor why the eccentricity of its orbit should be so low. Theory shows that if it were thrown off from

the sun it would periodically return nearly to the same point. Finally, the hypothesis of Buffon does not explain the abrupt transition in respect to eccentricity between the orbits of the planets and those of the comets.

1. *Former Expansion of the Solar Atmosphere.* — "Whatever the nature of the common cause of the planetary movements, since it has produced or directed these movements it must of necessity have embraced all the planetary bodies; and, considering the prodigious distances which separate them, it could have been nothing else than a fluid of immense extent. In order to have given them an almost circular motion in a uniform direction about the sun, this fluid must have surrounded the solar body like an atmosphere. The consideration of the planetary movements leads us, then, to think that, in consequence of its excessive heat, the atmosphere of the sun extended formerly beyond the orbits of all the planets, and that it contracted by degrees to its present limits."

"In this primitive state of the sun it resembled the nebulæ which the telescope reveals to us composed of a more or less brilliant nucleus, surrounded by a nebulosity which, by condensation upon the surface of the nucleus, transforms it into a star. If, by analogy, we conceive all the stars formed in this manner, we can imagine their former state of nebulosity itself preceded by other states in which the nebulous matter was more and more diffuse, the nucleus being less and less luminous. We arrive thus, in receding as far as possible, at a nebulosity so diffuse that its existence is barely imaginable."

Mitchel long since remarked that the grouping of the Pleiades could not be the result of chance; and the same may be said of all clusters of stars. They must be "the effects of a primitive cause or general law of nature. Such groups are the necessary result of the condensation of nebulæ about numerous nuclei."

2. *Formation and Abandonment of Zones of Vapor.* — "But how did the solar atmosphere determine the motions of rotation and revolution of the planets and satellites? If these bodies had been profoundly immersed in this atmosphere, its resistance would have caused them to fall upon the sun. We are compelled to assume, therefore, that the planets have been formed at their successive limits by the condensation of zones of vapors which, in the process of cooling, it must have abandoned in the plane of its equator."

"Let us recall now the results presented in the tenth chapter of the preceding book. The atmosphere of the sun could not extend outward indefinitely; its limit would be the point where the centrifugal force due to its movement of rotation would counterbalance gravitation. But, in proportion as cooling contracted the atmosphere, and condensed at the surface of the body the molecules located in that region, the movement of rotation increased by virtue of the principle of areas." The centrifugal force due to increased rotation becoming increased, the point where gravity equals it would be nearer the centre. In short, a process of annulation would begin and proceed.*

The zones of vapors necessarily abandoned "must probably, by their condensation and the mutual attraction of their molecules, have formed different concentric rings of vapors circulating about the sun. The mutual friction of the molecules of each ring must have accelerated some and retarded others, until all should have acquired the same angular motion. Thus the actual velocities of the molecules most remote from the sun have been the greater. The following cause must have further contributed to this difference of velocities: The molecules farthest removed from the sun, and which, in the progress of cooling and condensation, must have formed the exterior portion of

* In the way which I have elsewhere explained, following Laplace.

the ring, have always described areas proportional to the times, since the central force which actuated them has been constantly directed toward the solar centre; but this constancy of areas demands an acceleration of velocity in proportion as the molecules are condensed. It is apparent that the same cause must have diminished the velocity of the molecules which constitute the interior border of the ring."

3. *Rupture and Planetation of Rings.*— Proceeding to the subsequent history of a ring, the author shows that the conditions of its permanence can very rarely exist. "Almost always each ring of vapors must have broken up into numerous masses, which, moving with a nearly uniform velocity, must have continued to circulate at the same distance around the sun. These masses must have taken a spheroidal form, with a motion of rotation in the same direction as their revolution, since the inner molecules [those nearest the sun] would have less actual velocity than the exterior ones. They must then have formed as many planets in a state of vapor. But if one of them was sufficiently powerful to unite successively, by its attraction, all the others around its centre, the ring of vapors must have been thus transformed into a single spheroidal mass of vapors circulating around the sun with a rotation in the same direction as its revolution. The latter case has been the more common, but the solar system presents us the first case in the four small planets* which move between Jupiter and Mars."

The author then traces the same process in the history of these planetary globes of fire mist. "The regular distribution of the mass of the rings of Saturn around his centre and in the plane of his equator, results naturally from this hypothesis, and without it would be inexplicable. These rings appear to me to be proofs ever-exist-

* All the asteroids then known.

ing of the primitive extension of Saturn's atmosphere and its successive retreats." Thus the remarkable uniformities in planetary conditions and movements "flow from the hypothesis which we offer, and give it a strong probability of truth."

The diverse inclinations and eccentricities of the planetary orbits are attributed to the "numberless variations which must have existed in the temperature and density of the different parts of the large masses."

4. *Relations of Comets and Zodiacal Light.*—"In our hypothesis," the author concludes, "the comets are strangers to the planetary system."* The great eccentricity of their orbits, as well as their various inclinations, is a consequence of the present hypothesis. "The attraction of the planets, and perhaps also the resistance of the ethereal medium must have changed many cometary orbits into ellipses whose longer axis is much less than the radius of the sun's activity." "If any comets penetrated the atmospheres of the sun and planets during the time of their formation, the former must have been precipitated in spiral paths upon these bodies, and by their fall have displaced the planes of the orbit and of the equators of the planets from the plane of the solar equator."

"If, in the zone abandoned by the atmosphere of the sun, there existed molecules too volatile to be united among themselves or with the planets, they must have continued to circulate about the sun under an aspect such as the zodiacal light presents, but with too great tenuity to oppose any sensible resistance to the various bodies of the planetary system, a result which would also flow from a motion in the same direction as that of the planets."

5. *Lunar Synchronistic Motions.*—"A profound examination of all the circumstances of this system increases

* See the full passage quoted above, p. 182.

still farther the probability of our hypothesis. The primitive fluidity of the planets is clearly indicated by the flattening of their figure." The vicissitudes of geological history and the nature of the succession of animals and plants upon the earth, similarly testify to a progressive reduction of temperature.

"One of the most singular phenomena of the solar system is the rigorous equality observed between the angular motions of rotation and the orbital revolutions of the several satellites. The probability is as infinity to one that this is not the result of chance. The theory of universal gravitation causes this improbability to disappear by showing that it suffices for the existence of this phenomenon that in the beginning these movements should have been but slightly different. At that time the attraction of the planet established between them a perfect equality, but at the same time, it gave birth to a periodic oscillation of the axis of the satellite directed toward the planet. The extent of this oscillation would depend on the primitive difference of the two movements. The observations of Mayer on the libration of the moon, and those which MM. Bouvard and Nicollet have made on this subject at my request, not having led to the discovery of such an oscillation, the difference on which it depends must have been very small. This circumstance indicates with extreme probability a special cause which originally embraced this difference within very narrow limits where the attraction of the planet has been able to establish between the *mean* motions of rotation and revolution a rigorous equality, and has subsequently acted until it destroyed the oscillation to which this equality had given origin. Both these effects result from our hypothesis, for we conceive that the moon in the state of vapor, assumed through the powerful attraction of the earth, the form of an elongated spheroid whose longer axis was directed con-

stantly toward this planet. This would result from the readiness with which vapors yield to the feeblest forces acting upon them. Terrestrial attraction continuing to act in the same manner as long as the moon was in a fluid state, must at length by continually approximating the periods of the two motions of this satellite, have caused their difference to fall within the limits where their rigorous equality began to be established. Subsequently, this attraction must have destroyed, little by little, the oscillation which this inequality produced in the longer axis of the spheroid directed toward the earth. In the same way, the fluids which cover this planet have destroyed by their friction and by their resistance the primitive oscillations of its axis of rotation ; for this is now subjected only to the nutation resulting from the actions of the sun and moon."

The well known remarkable relation between the orbital motions of Jupiter's satellites is explained on the nebular hypothesis in a manner precisely similar.

CHAPTER V.

SYSTEMATIC RÉSUMÉ OF OPINIONS.

THE foregoing sketch of opinions shows that

1. The two fundamental conceptions of nebular cosmogony have been in existence ever since the dawn of Greek philosophy. These are: (1) The conception of widely extended, unorganized, homogeneous matter, which the Greeks called *Chaos*, and most late writers have identified with the *nebular* condition of matter; (2) A *vortical* movement as the occasion and cause of the differentiations of atoms and parts, and the organization of structural order.

2. The theory as here accepted is most nearly that which was promulgated by Laplace; but it contains probably a greater amount of matter which was original with Kant.

3. The modern theory was impossible until Newton had demonstrated the principle of universal attraction, and Newton and the brilliant mathematicians of the eighteenth century had settled analytically the dynamical principles of the solar system, and Sir William Herschel had given the world some adequate knowledge of nebular and firmamental relations. Nor was the modern theory possible until the mechanical doctrine of heat, and the general doctrine of the conservation of energy, and the kinetic theory of gases had been firmly established. A whole constellation of original thinkers have therefore brought their respective contributions to the perfection and confirmation of the generally accepted doctrine of cosmogenesis.

The part which the several cosmogonic systems and conceptions contributed to the modern theory may perhaps be most intelligibly set forth in an enumeration of the constitutive principles of general nebular cosmogony.

1. A HOMOGENEOUS MEDIUM.

Chaos. 1. *A Continuous substance.* Anaxagoras (*Homœomeria*) Descartes. Compare the "primitive fluid" of Sir W. Thomson.

2. *An Atomic medium.* Leucippus, Democritus, Epicurus, Lucretius and other Greek atomists. Newton and most moderns. Compare the "monads" of Leibnitz.

3. *Dynamical molecules.* Boscovich, ? Faraday. Compare the "vortical atoms" of Sir W. Thomson.

Solar emanation. Kepler. But the sun and planets are supposed already existent.

Plenum of matter becoming differentiated into Particles. Descartes.

Ethereal Fluid. Leibnitz. But the planets already assumed to be in existence.

An infinitude of Atomic Vortices. Swedenborg.

Primitive fluid formed of all the matter of the solar system dissolved into its elements. Kant.

Nebulous Matter existing in finite regions of space. Huygens, Sir William Herschel, Laplace.

Disappearance of the medium on Formation of Planets. Kant, Laplace.

2. VORTICAL MOTION.

Revolution of the Heavens. Egyptians, Chaldæans and Greeks.

Rotation of the Earth. Hicetas, Ecphantus, Heraclides, Cusanus.

Revolution of the Earth. Aristarchus, Seleucus, Archimedes, Aryabatta, Copernicus.

Elemental Vortices. 1. *Inaugurated by The Mind.* Anaxagoras. Torricelli, Galileo, Descartes, Swedenborg. Compare "Vortical Atoms" by Sir William Thomson.

2. *Existing from eternity.* Leucippus, Democritus.

3. *Originated by self determination.* Epicurus, Lucretius, Gassendi, Leibnitz, Rosmini, Campanella.

Systemic Vortices. 1. *One Solar Vortex.* Kepler.

2. *Planetary and Solar Vortices.*

(a.) *Origin not explained on Mechanical Principles.* Descartes, Leibnitz, Swedenborg, Wright, Lambert.

(b.) *The result of mechanical action.* Kant, Laplace (except solar rotation).

Nebular Vortices. Kant, Herschel, Laplace.

[*Firmamental Rotation.* Wright, Kant, Lambert.]

Orbital Movement of Our Sun in Space. Laplace, Herschel (not stated to be *orbital*).

3. UNIVERSAL CONCURRENCE OF MATTER.

Love, with its antithesis, Hate. Empedocles.

Cosmical Magnetism. Kepler (who utilized *attraction* and *repulsion*), Swedenborg.

Universal Attraction. Newton, Wright, Kant, Lambert, Herschel, Laplace.

Pressure and Impulse. 1. *From a cosmical fluid.* Descartes, Leibnitz.

2. *Storm of "ultramundane corpuscles."* Le Sage.*

Consequent central Condensation. Kant (except *at* the centre), Herschel (in nebulæ).

Consequent Heat and Luminosity. Lichtenberg, Kant.

4. THERMAL RADIATION AND CONTRACTION.

Condensation around Solar and Planetary Centres. Kant, Laplace.

Heat and Luminosity maintained. Helmholtz, etc.

5. ANNULATION.

One Equatorial Ring accumulated. Swedenborg.

Saturnian Ring thrown off (possibly other planetary rings). Kant.

Successive Solar Equatorial Rings abandoned. Laplace.

Stratification of Rings. Kant (in respect to Saturn's), Laplace.

Saturnian Rings but Swarms of small Satellites. Cassini, Kant, Peirce, Clerk-Maxwell.

The Zodiacal Light a similar Ring. Kant, Laplace.

Annulation in existing Nebulæ. Herschel.

6. SPHERATION OF RINGS.

One Ring disrupted formed the Several Planets, which were thrown outward to their respective positions. Swedenborg.

Each of Several Rings gathered into a planetary mass. Laplace.

* Le Sage: *Lucrèce Newtonien: Traité de Physique Mécanique*, Geneva, 1818. See also *Constitution de la Matière*, etc., par le P. Leray, Paris, 1869, and Tait's *Recent Advances in Physical Science*, 299.

In one instance a ring resulted in Numerous Asteroids. Laplace.
The Asteroids may have resulted from a Stratified Ring.

7. EFFECTS OF PERTURBATIVE ATTRACTIONS.

Inclinations of Planetary Axes. Kant, Laplace (who also appeals to cometary precipitation).
Eccentricities of Orbits. Laplace.

8. DISLOCATIONS OF PLANETARY CRUSTS.

Orographic Inequalities caused by confined gases. Leibnitz, Kant.

9. GENERALIZATION OF COSMIC HISTORY.

Successive Stages of Star and Planet formation from a nebula — a planet a cooled sun. Leibnitz, Kant, Herschel, Laplace.
Jupiter in an early stage of development. Kant.
The Moon in a fossilized condition. Frankland.*
Other planets habitable, or destined to be so. Kant, Lambert, Herschel, Laplace.
The various Colors of the Stars indicative of successive Stages. Laplace, Secchi.†

10. CYCLES OF COSMIC EXISTENCE.

Decay of Worlds in one region compensated by New Organisms in another. Kant, Herschel.
Occasional Revival of waning suns. Kant, Herschel.
Resuscitation of Cosmic Organisms by Precipitation and Impact. Kant.

* *Proc. Roy. Inst.*, iv, 175. The idea was advanced in the present writer's *Sketches of Creation*, in March, 1870. Compare L. Sæmann: *On the Unity of Geological Phenomena in the Solar System*, Bull. de la Soc. géol. de France, 4 Feb., 1861; J. Nasmyth: *On the Age of the Moon's Surface*, Proc. Manchester Lit. and Phil. Soc., Nov. 15, 1864.

† Secchi: *Le Soleil.*

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